Higgins' Eye Pearlymussel
(*Lampsilis higginsii*)
Draft Recovery Plan: First Revision

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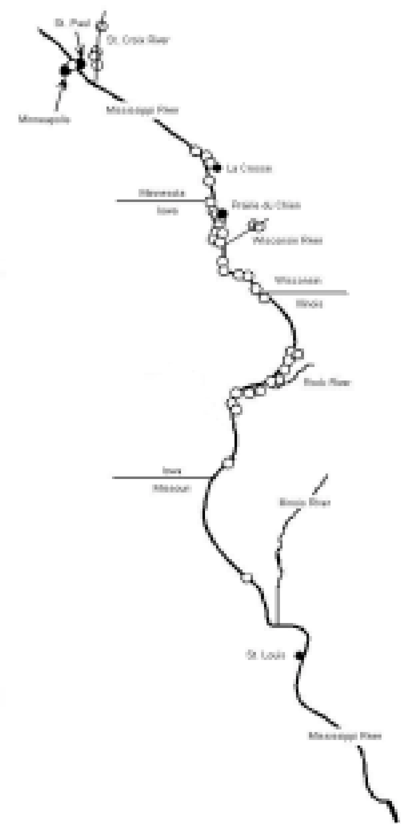

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U.S. Department of Interior
U.S. Fish and Wildlife Service
Great Lakes/Big Rivers Region
Ft. Snelling, Minnesota

Higgins' Eye Pearlymussel (*Lampsilis higginsii*)
Draft Recovery Plan: First Revision

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Date: ____

DISCLAIMER

Recovery plans delineate reasonable actions which are believed to be required to recover and/or protect listed species. Plans are published by the U.S. Fish and Wildlife Service (USFWS), sometimes prepared with the assistance of recovery teams, contractors, state agencies, and others. Objectives will be attained and any necessary funds made available subject to budgetary and other constraints affecting the parties involved, as well as the need to address other priorities. Recovery plans do not necessarily represent the views nor the official positions or approval of any individuals or agencies involved in the plan formulation, other than the USFWS. They represent the official position of the USFWS only after they have been signed by the Regional Director or Director as approved. Approved recovery plans are subject to modification as dictated by new findings, changes in species status, and the completion of recovery tasks.

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Recovery plans can be downloaded from USFWS website: http://endangered.fws.gov.

ACKNOWLEDGMENTS

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EXECUTIVE SUMMARY

Current Species Status

This species is currently listed as endangered. Studies before 1993 indicate healthy populations of *Lampsilis higginsii* in the Upper Mississippi River drainage, with no apparent significant declines in its distribution or abundance. In fact, new information since completion of the first recovery plan in 1983 has extended its known range by 180 river miles.

There was concern, however, that a major flood in 1993, as well as an infestation of the non-native zebra mussel (*Dreissena polymorpha*), may pose serious threats to the continued existence of this species. In response to these threats and information, the recovery team was constituted to review the status of the species and to revise the initial recovery plan if necessary. The team commissioned a review of all research conducted on the species since 1980, as well as a survey of all sites designated as Essential Habitat Areas in the 1983 recovery plan. During the development of this revised recovery plan, new information suggesting a significant impact of zebra mussels on *Lampsilis higginsii* came forward and the team believes there is now a significant risk that the distribution and abundance of this species will be severely compromised.

The initial Higgins' Eye Pearlymussel Recovery Plan listed seven locations as primary habitats (called Essential Habitat Areas in this document) and nine locations as potential secondary habitats. This revised plan includes ten Essential Habitat Areas -- six in the Mississippi River between river miles 489 (Sylvan Slough) and 656 (Whiskey Rock), one in the Wisconsin River (Orion), and three in the St. Croix River, which empties into the Mississippi River at river mile 811. Cawley (1996) indicated that since 1980, all seven of the Essential Habitat Areas in the initial Higgins' Eye Pearlymussel Recovery Plan had been sampled. In addition, six of the nine secondary habitats had been sampled. *L. higginsii* also occurs elsewhere in the Mississippi River, and this revised plan recommends that surveys be conducted in several specific areas to better describe other potentially important habitats.

Since zebra mussels invaded the Mississippi River in the early 1990's, three of the Essential Habitat Areas, East Channel (Prairie du Chien), Harpers Slough, and Cordova have become severely infested with zebra mussels; only one Essential Habitat Area, Interstate Park (St. Croix River) is entirely free of zebra mussels. There are currently no effective methods to control established populations of zebra mussels of the scale and nature necessary to nullify their threat to *L. higginsii* in the Mississippi River. Since 2000, *L. higginsii* has been reintroduced into four rivers from which it had been extirpated, but it is too soon to determine whether these efforts have resulted in the successful reestablishment of the species.

Habitat Requirements and Limiting Factors

Lampsilis higginsii is characterized as a large river species occupying stable substrates that vary from sand to boulders, but not firmly packed clay, flocculent silt, organic material, bedrock, concrete or unstable sand. Water velocities should be less than 1 m/s during periods of low discharge. They are usually found in mussel beds that contain at least 15 other species at densities greater than .01 individual/m^2. The density of all mussels in the bed typically exceeds 10/m^2.

The ten identified Essential Habitat Areas are: The Mississippi River at Lansing, Iowa (Whiskey Rock); near Harper's Ferry, Iowa (Harper's Slough); the main and east channel areas at Prairie du Chien, Wisconsin; near Guttenberg, Iowa (McMillan Island); Cordova, Illinois; Moline, Illinois (Sylvan Slough); the St. Croix River at Prescott, Wisconsin, at Hudson, Wisconsin, and near Taylor's Falls, Minnesota (Interstate Park); the Wisconsin River near Muscoda, Wisconsin (Orion mussel assemblage). Zebra mussels have severely degraded the mussel communities at a few of these areas to the degree that they may no longer support dense and diverse mussel beds. Each of these areas, however, demonstrated its importance to the conservation of *Lampsilis higginsii* before zebra mussel infestation and zebra mussels are the only factor that has, at least temporarily, degraded their ability to support stable or growing populations of *Lampsilis higginsii*. Therefore, we will retain each of these areas as Essential Habitat due to their historical importance to the species and the uncertainty regarding their potential to recover from the effects of zebra mussels. Any areas not designated in this plan as Essential Habitat, however, must meet this plan's definition of Essential Habitat to be designated as such. The USFWS's Twin Cities Field Office will retain an up-to-date list of Essential Habitat Areas.

Recovery Strategy

This revised recovery plan adopts the approach of the previous recovery plan for *L. higginsii* by focusing recovery on the conservation of the species at identified Essential Habitat Areas. In the 1983 recovery plan, Essential Habitat Areas were specific areas throughout the historical range of *L. higginsii* that supported dense and diverse mussel beds where *L. higginsii* was successfully reproducing. This revised recovery plan identifies three additional "Essential Habitat Areas" (Orion, WI, Prescott, WI, and Interstate Park, MN/WI), but also outlines specific criteria for evaluating additional areas for this designation. The plan recommends the development of a uniform protocol for collecting information on populations of *L. higginsii*. Use of this protocol will allow for ongoing evaluation of the list of Essential Habitat Areas and progress towards recovery.

The highest priority recovery actions for *L. higginsii* are primarily intended to address the severe impacts and threats posed by zebra mussels. Of the ten Essential Habitat Areas designated in this revised plan, zebra mussels have had severe impacts on the mussel communities at Harpers Slough, Prairie du Chien, and Cordova and are imminent threats at the Prescott, and Hudson, WI areas. The Prairie du Chien Essential Habitat Area, for example, may have contained the largest population of *L. higginsii* before its severe infestation by zebra mussels, but Miller and Payne (2001) found nearly 10,000 zebra mussels/m^2 in this area in 2000.

The removal of zebra mussels in a manner and scale necessary to benefit *L. higginsii* is evidently not currently feasible. Therefore, the plan focuses on developing methods to prevent new infestations, monitoring zebra mussels at Essential Habitat Areas, and developing and implementing contingency plans to alleviate impacts to infested populations. Based on recent activities, the latter may consist largely of removing *L. higginsii* from areas where zebra mussels pose an imminent risk to the persistence of the population and releasing them into suitable habitats within their historical range where zebra mussels are not an imminent threat. Within the last two years, workers have removed 471 adult *L. higginsii* from areas near Cassville, WI and Cordova, IL on the Upper Mississippi River and relocated them into Pools 2 and 3 near Minneapolis, MN and Hastings, MN, respectively (Table 1). Cleaning fouled adults *in situ* and artificial propagation and release (Table 1) are also currently being implemented in an attempt to alleviate the effects of zebra mussels on the conservation of *L. higginsii*.

Although zebra mussels are currently the most important threat to *L. higginsii*, construction activities and environmental contaminants may also pose significant threats. Therefore, the Corps and other agencies must continue to assess and limit the potential impacts of their actions on *L. higginsii*. The plan also outlines tasks needed to improve our understanding of the potential importance that contaminants play in the conservation of *L. higginsii* and calls on the U.S. Coast Guard, Environmental Protection Agency, and other agencies to take actions to minimize the potential impacts of toxic spills.

Interagency partnerships will be key to the recovery of *L. higginsii*. In addition to the USFWS, the Implementation Table identifies five other federal agencies and four states as being responsible for various aspects of the recovery of the species. The U.S. Army Corps of Engineers, for example, is called on to implement several of the tasks. The Corps' implementation of the 2000 Biological Opinion on continued operation and maintenance and operation of the 9-foot navigation channel has resulted in the formation of the Mussel Coordination Team (MCT). This MCT has implemented extensive relocation and reintroduction of *L. higginsii* since 2000 (Table 1). These activities, although necessary to avoid jeopardizing the species, are leading to the development and refinement of techniques for propagating *L. higginsii* and other mussel species.

Recovery Goals and Interim Recovery Criteria

The criteria for meeting the recovery goals are interim because further work (see below) is necessary to make them fully measurable. The tasks that are necessary to make the criteria fully measurable are outlined below and are included in the Narrative Outline for Recovery Activities and in the Implementation Table.

Goal 1: Reclassify *Lampsilis higginsii* to Threatened Status

Interim Criteria for Goal 1 (Reclassification)

1. *Lampsilis higginsii* may be considered for reclassification from Endangered to Threatened when at least five identified Essential Habitat Areas contain reproducing, self-sustaining populations of *L. higginsii* that are not threatened by zebra mussels. The five Essential Habitat Areas include the Prairie du Chien Essential Habitat Area and at

least one Essential Habitat Area each in the St. Croix River and in Mississippi River Pool 14.

a. *L. higginsii* populations will be considered to be "reproducing" if there is evidence that they include a sufficient number of strong juvenile year classes.[1]

b. Populations will be considered to be "self-sustaining" if they have maintained stable or increasing population densities for at least twenty years.

c. Each identified Essential Habitat Area will be considered to be "not threatened by zebra mussels" if zebra mussel densities have not increased for five consecutive years.[2] This criterion will not be met if there is one or more newly discovered or expanded population of zebra mussels in a location where they or their offspring may affect *L. higginsii* populations in one or more of the identified Essential Habitat Areas. The USFWS will make this determination by evaluating water velocities, larval development times, and distances between any newly discovered or expanded zebra mussel population and any of the five identified Essential Habitat Areas. If there is a possibility that veligers from any newly discovered or expanded zebra mussel population will settle in any of the identified Essential Habitat Areas, this recovery criterion will not be met until an additional three years of zebra mussel sampling indicates that zebra mussel densities are not increasing in any of the potentially affected Essential Habitat Areas.

The following questions must be answered to make this criterion fully measurable. These are included in the Narrative Outline for Recovery Activities and in the Implementation Table as part of Task 1.2.2, a Priority 1 task.

i. What would constitute sufficient evidence of a strong juvenile year class?

ii. What methods should be used to evaluate the strength of juvenile year classes?

iii. How many strong juvenile year classes should be detected to determine that reproduction is sufficient to allow for stable or growing populations?

2. Complete the following tasks to determine if water quality criteria for Goal 2 (Delisting) are necessary to ensure the conservation of *L. higginsii* and, if so, to develop measurable water quality criteria for Goal 2.

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[1] *L. higginsii* less than 20 mm in length will be assumed to be juveniles.

[2] For analyses of zebra mussel and *L. higginsii* population trends, use a significance level (ζ)#Ω0.2 and power#∅0.9 for all tests.

a. 1.5.1. Develop a freshwater mussel toxicity database for sediment and water quality parameters to define *L. higginsii* habitat quality goals. (7 sub-tasks)

b. 1.5.2. Characterize specific sediment and water quality parameters in the ten *L. higginsii* Essential Habitat Areas. (1 sub-task)

3. Harvest of freshwater mussels is prohibited by law or regulation in Essential Habitat Areas. This applies to all Essential Habitat Areas, not just the five identified under criterion 1.

Goal 2: Delist *L. higginsii.*

Interim Criteria for Goal 2 (Delisting)

1. Delisting *L. higginsii* requires that populations of *L. higginsii* in at least five Essential Habitat Areas are reproducing, self-sustaining, not threatened by zebra mussels, and are sufficiently secure to assure long-term viability of the species. The five Essential Habitat Areas include the Prairie du Chien Essential Habitat Area and at least one Essential Habitat Area each in the St. Croix River and in Mississippi River Pool 14. "Reproducing" and “self-sustaining” are to be fully defined above under Goal 1.

   Populations at the identified Essential Habitat Areas will be “sufficiently secure to assure long-term viability of the species” if each of the following four conditions is met:

   a. There is no indication that activities that are reasonably likely to occur in the foreseeable future will result in a change in the predominant substrate conditions within each identified Essential Habitat Area to shifting, unstable sands, silt, cobble, boulder, artificial substrates (*e.g.*, concrete), or substrates with rooted plants to the extent that such changes would appreciably reduce the likelihood of conserving the *L. higginsii* population in the Essential Habitat Area.

   b. There is no indication that activities that are reasonably likely to occur in the foreseeable future will result in water quality characteristics (*e.g.*, high concentrations of un-ionized ammonia) in Essential Habitat Areas that have been shown to cause detrimental effects to *L. higginsii* or sympatric species to the extent that such effects would appreciably reduce the likelihood of conserving the *L. higginsii* population in the Essential Habitat Area.

   c. There is no indication that construction of barge loading or off-loading sites, boat harbors, highway bridges, or fleeting areas or dredging of access channels are reasonably likely to occur in the foreseeable future within the identified Essential Habitat Areas to the extent that such construction or dredging activities would appreciably reduce the likelihood of conserving the *L. higginsii* population in the Essential Habitat Area.

d. Measures that provide for review of federally funded, permitted, or planned activities in or near *L. higginsii* habitat pursuant to the Fish and Wildlife Coordination Act and Clean Water Act are in place.

2. Each identified Essential Habitat Area will be considered to be "not threatened by zebra mussels" if zebra mussel densities have not increased for five consecutive years.[3] This criterion will not be met if there is one or more newly discovered or expanded population of zebra mussels in a location where they or their offspring may affect *L. higginsii* populations in one or more of the identified Essential Habitat Areas. The USFWS will make this determination by evaluating water velocities, larval development times, and distances between any newly discovered or expanded zebra mussel population and any of the five identified Essential Habitat Areas. If there is a possibility that veligers from any newly discovered or expanded zebra mussel population will settle in any of the identified Essential Habitat Areas, this recovery criterion will not be met until an additional three years of zebra mussel sampling indicates that zebra mussel densities are not increasing in any of the potentially affected Essential Habitat Areas.

3. The use of double hull barges is required at and upstream of each of the identified Essential Habitat Areas that may otherwise be threatened by spills from commercial barges.

4. *L. higginsii* habitat information and protective responses to conserve each of the identified Essential Habitat Areas have been incorporated into all applicable spill contingency planning efforts.

5. Harvest of freshwater mussels is prohibited by law or regulation in Essential Habitat Areas. This applies to all Essential Habitat Areas, not just the five identified under criteria numbers 1-4.

6. Water quality criteria may be added to the criteria for Goal 2 (Delisting) upon completion of the tasks referred to under the Criteria for Goal 1 (Reclassification, see 2a-b above and Tasks 1.5.1 and 1.5.2).

<u>Actions Needed:</u> The recovery plan is organized around two main objectives: 1) Preserving *L. higginsii* and its Essential Habitat Areas and 2) Enhancing the abundance and viability of *L. higginsii* in areas where it currently exists and restoring populations within its historical range.

1) Preserving the current populations of *L. higginsii* and its Essential Habitat Areas requires the following actions:

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[3] For analyses of zebra mussel and *L. higginsii* population trends, use a significance level /ζ0⊭Ω0.2 and power ∅0.9 for all tests.

A. Limit the impact of the exotic bivalve, the zebra mussel, *Dreissena polymorpha*.
B. Develop uniform protocols for collecting and maintaining information on *L. higginsii* populations.
C. Confirm and modify the list of seven Essential Habitat Areas in the initial recovery plan.
D. Limit construction in areas of essential *L. higginsii* habitat. Mitigation, including translocation, may be an acceptable alternative in limited instances.
E. Continue to examine the relationship between water quality, especially contaminants, and *L. higginsii* populations in Essential Habitat Areas.
F. Develop plans to reduce the shipment of toxic materials near *L. higginsii* habitat and develop response plans for any spills that may occur.
G. Review current regulations and develop additional regulation of mussel harvest in the upper Mississippi River drainage to reduce impacts on *L. higginsii*.
H. Develop materials to educate the public on the nature of endangered mussels and *L. higginsii*, in particular.

2) Enhancing and restoring populations of *L. higginsii* within its historic range requires the following actions:

A. Identify and rank potential sites of existing *L. higginsii* populations for enhancement.
B. Increase the number of *L. higginsii* at enhancement sites to current levels found in Essential Habitat Areas or to numbers appropriate for the local habitat.
C. Determine the feasibility of reestablishing *L. higginsii* into historic habitats, particularly streams that are at lower risk for zebra mussel colonization and carry out reintroduction using the best available methods.
D. Examine the taxonomic validity of *L. higginsii* especially since *L. abrupta* is found in noncontiguous geographic areas.

Several specific actions are recommended for immediate implementation to ensure the survival of the *L. higginsii*.

A. Limit the impact of the exotic bivalve, the zebra mussel, *Dreissena polymorpha*.

B. Develop uniform protocols for collecting and maintaining information on *L. higginsii* populations.

C. Confirm and modify the seven locations listed in the initial recovery plan as Essential Habitat Areas.

D. Require the use of double hull barges.

Estimated Cost of Recovery for Fiscal Years 2004-2006 (in $1000s): Costs for fiscal years 2007-2054 will be determined on at least an annual basis by the USFWS and cooperating agencies.

Fiscal Year	Task 1.1	Task 1.2	Task 1.3	Task 1.4	Task 1.5	Task 1.6	Task 1.7	Task 1.8	**Total**
2004	100	160	290	50	745	40	0	10	**1395**
2005	120	160	280	50	745	40	0	0	**1395**
2006	70	110	270	50	470	40	0	0	**1010**
Total	**290**	**430**	**840**	**150**	**1960**	**120**	**0**	**10**	**3800**

The total costs for Goal 1, Years 1 - 3, do not include the cost of two tasks (1.4.1 and 1.4.2) which could not be determined at this time.

Date of Recovery: 2054, if recovery criteria are met and if fully funded.

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I. INTRODUCTION

The Higgins' eye pearlymussel (*Lampsilis higginsii*, Lea 1857) was federally listed as an endangered species June 14, 1976 (41 FR 24064). The first Federal recovery plan was approved on July 29, 1983. Revision of the 1983 plan began in 1994, in the wake of the Great Flood of 1993. There was concern that the flooding may have significantly impacted *L. higginsii.* This revision is part of the USFWS's ongoing revision of recovery plans, and it supersedes the initial 1983 recovery plan.

Description of *Lampsilis higginsii*

<u>Taxonomy and Systematics</u>

Phylum: Mollusca
Class: Bivalvia
Order: Unionoida
Family: Unionidae
Genus: *Lampsilis*
Species: *higginsii* (Lea 1857)

The type locality for *L. higginsii* is the Mississippi River at Muscatine, Iowa (USFWS 1983). The original species name given was *higginsii*, but many references, including the original listing document, gives the spelling as *higginsi*. Turgeon *et al.* (1998) indicate that the proper name is *Lampsilis higginsii* with the common name for the species being the Higgins' Eye. This species belongs to a morphologically variable, geographically widespread genus. Most malacologists agree that *L. higginsii* is a valid species. There was some early confusion between *L. higginsii* and the morphologically similar *L. abrupta* (the pink mucket pearly mussel -- also on the Federal Endangered and Threatened Species list). *Lampsilis abrupta* is distributed further to the south, and *L. higginsii* is found only in the Upper Mississippi River Basin (Oesch 1984). Johnson (1980) discusses the similarities and differences between *L. abrupta* and *L. higginsii* but there is still some controversy surrounding the taxonomic status of these species.

<u>Morphological Description</u>

Baker (1928) provided a general description of the shell morphology. Baker stated that the shell was: "Oval or elliptical, somewhat inflated, solid, with gaping anterior base; beaks placed forward of the center of the dorsal margin, much elevated, swollen, their sculpture consisting of a few feeble ridges slightly looped; anterior end broadly rounded; posterior end truncated in the female, bluntly pointed in the male; ventral and dorsal margins slightly curved, almost parallel; posterior ridge rounded, but well marked; surface shining, marked by irregular growth lines which are better developed at rest periods where they are usually dark colored; epidermis olive or yellowish-green with faint green rays. Hinge massive; pseudocardinals erect, triangular or pyramidal, divergent, serrated, two in the left and one in the right valve, with sometimes indications of additional denticles on either side of the single right pseudocardinal; interdentium narrow, flat; laterals short, thick, slightly curved, almost smooth; cavity of the beaks deep, containing the dorsal muscle scars; anterior adductor scar deeply excavated, posterior scar distinct; nacre silvery-white, iridescent, often tinged with pink."

This species exhibits marked sexual dimorphism with the posterior end in the females sharply truncated with a post-basal swelling. The posterior end in the males is more roundly pointed. A number of species can be confused with *L. higginsii*. Those cited as most similar are *Obovaria olivaria*, *L. cardium*, *L. siliquoidea, L. abrupta* and *Actinonaias ligamentina* (Baker 1928; Cummings and Mayer 1992). Although nothing has been published specifically on the internal anatomy of *L. higginsii*, Baker (1928) indicates it is most likely similar to that of other lampsilines.

Historical and Present Distributions

In the initial Higgins' Eye Pearlymussel Recovery Plan (USFWS 1983), the historic distribution of *L. higginsii* before 1965 was given as the main stem of the Mississippi River from just north of St. Louis, Missouri, to just south of St. Paul, Minnesota; in the Illinois, Sangamon, and Rock Rivers in Illinois; in the Iowa, Cedar, and Wapsipinicon Rivers in Iowa; in the Wisconsin and St. Croix rivers in Wisconsin; and, in the Minnesota River in Minnesota (based on Havlik 1980). A questionable report of this species in the lower Ohio River was also given (Havlik 1980). The initial plan also indicated a great reduction in the range of *L. higginsii* based on studies from 1965 through 1981 (Larsen and Holzer 1978; Mathiak 1979; Perry 1979; Havlik 1980; Fuller 1980; Thiel *et al.* 1980; Thiel 1981; Ecological Analysts 1981a).

Since the 1983 Recovery Plan, a number of studies have provided new information on the distribution and abundance of *L. higginsii*. A study by Cawley (1996) commissioned by the USFWS for the current recovery team provided a review of the information on *L. higginsii* distribution from 1980-1996. Cawley (1996) noted that 510 specimens of *L. higginsii* had been collected since 1980. Cawley (1996) extended the reported range of *L. higginsii* 98 miles to the south and 82 miles to the north based on the collection of dead specimens. Figure 1 (see Section V) summarizes the distributional data before 1965, from 1965-1980 and 1981-1996 based on the 1983 Recovery Plan and Cawley's (1996) study. Thiel (1981) stated that Pool 10 of the Mississippi River supported the largest population of *L. higginsii*. The area in the East Channel of the Mississippi River, by Prairie du Chien, Wisconsin, was considered to be the most productive *L. higginsii* habitat in the Mississippi River system. Cawley's (1996) review supports this assessment. Since Cawley's (1996) review, however, zebra mussels (*Dreissena polymorpha)* have drastically reduced the population of *L. higginsii* in the East Channel at Prairie du Chien.

Based on Cawley's (1996) review, it appears that there has been recent recruitment of *L. higginsii* (individuals <30 mm in shell length) in locations surveyed since 1980. The age distribution indicated that there are more middle-age mussels (35-85 mm shell length) than young. Miller and Payne (1988) indicated that some mussel species display infrequent, but fairly strong, recruitment and that there can be substantial variability in recruitment among closely located sites. Given that Cawley's (1996) review included a wide variety of sites examined over a number of years, the actual size distribution of *L. higginsii* populations is unknown at this time.

As mentioned above, one reason for examining the current status of *L. higginsii* was the Great Flood of 1993. Clarke and Loter (1992, 1993, 1994, 1995) have been monitoring the population of *L. higginsii* at Prairie du Chien, Wisconsin, since 1990 as part of a study designed to examine the impacts of barge traffic on mussels. Based on their results, it appears that the flood caused no significant change in the number of *L. higginsii* found, while recruitment of some other mussel species was reduced in 1994. Recruitment varied among years (Miller and Payne 1991, 1992, 1993, 1994, 1995a,b, 1996a, 1997), and thus a cause-effect relationship cannot necessarily be inferred from Clark and Loter's (1995) work. Mussel communities may have been slightly relocated due to the flood.

This recovery team commissioned four studies, funded by the USFWS, to examine *L. higginsii* populations. The major objective of these studies was to examine what impact, if any, the 1993 floods in the Upper Mississippi River and its tributaries had on *L. higginsii*. These studies were conducted by Davis and Hart (1995), Heath (1995), Hornbach *et al.* (1995) and Miller and Payne (1996b).

Heath (1995) sampled quantitatively and qualitatively for *L. higginsii* at the Orion mussel aggregation in the Wisconsin River. He indicated that there was suitable habitat at this site, with *L. higginsii* comprising between 0.08% and 0.21% of the community. There was some evidence of reproduction within the last decade; Heath estimated that there were 2,273 *L. higginsii* at this site.

Hornbach *et al.* (1995) examined *L. higginsii* populations in the St. Croix River and estimated populations to be 4,000 mussels at Franconia, 4,000 to 10,000 mussels at Prescott, Minnesota, and 238,000 to 260,000 mussels at Hudson, Wisconsin (all listed as Essential Habitat Areas in the initial recovery plan). Doolittle and Heath (1997), Heath (*in litt.* 1998), and Heath *et al.* (1999) collected almost 90 *L. higginsii* from 1987-1999 in the area of the St. Croix river, extending upstream of Franconia, MN to the Interstate Park Area (Taylor's Falls, MN) - about 3 river miles. They estimate *L. higginsii* population densities of approximately 0.01 individuals/m^2. In 2000, mean density estimates of *L. higginsii* at Interstate Park and Hudson were 0.01 and 0.09, respectively (Heath *et al.* 2001); these estimates did not reflect a statistically significant change in abundance at either site. Estimates of population size were 9,224 (95% CI = 4,192 - 14,255) at Hudson and 4,212 (95% CI = 358 - 7,886).

Miller and Payne (1996b) estimated that there were 40,000 m^2 of suitable habitat for *L. higginsii* at McMillan Island in Pool 10 of the Mississippi River near Guttenberg, Iowa, (an area designated as Essential Habitat Areas in the 1983 Recovery Plan) which contained an estimated 5,320 individuals. A more recent report contained revised estimates of both suitable habitat (860,994 m^2) and potential population size (662,965 individuals), although the authors suggest cautious interpretation of these crude estimates due to high levels of variability among the data (Miller and Payne 2001).

Davis and Hart (1995) examined an area downstream of Lock and Dam No. 6 on the Mississippi River near Trempealeau, Wisconsin, to determine whether this area should be classified as essential for *L. higginsii*. They found two live and two dead *L. higginsii* in the area. Although they did not estimate overall population size of *L. higginsii*, they indicated that because this area harbored many other mussel species at high densities, it has potential as an important area for *L. higginsii*. Unfortunately, at the four sites they examined, from 9 to 44% of all unionids were infested with zebra mussels.

Recent Reintroductions

Since 2000, state and federal conservation agencies have cooperated to reintroduce *Lampsilis higginsii* into areas that it occupied historically, but from which it had been extirpated. This work has largely been a result of a consultation between USFWS and the U.S. Army Corps of Engineers (Corps) under section 7(a)(2) of the Endangered Species Act (Act) on the effects to *Lampsilis higginsii* of the Corps' operation and maintenance of a nine-foot navigation channel on the Upper Mississippi River (see below). In 2000 and 2001, biologists relocated 471 adult *Lampsilis higginsii* from the Mississippi River at Cassville, WI and Cordova, IL where zebra mussels posed an imminent risk, and released them at two sites in Pools 2 and 3 of the Mississippi River where zebra mussel densities are below threatening levels. Davis (2003) examined 59 relocated females at these two sites in 2002 and found that about one-third were gravid. Of the 63 *L. higginsii* recovered in 2002 (59 females, 4 males), only one was found dead, although several had abnormal growth patterns exhibited by "exaggerated growth arrest lines and in-turning along the ventral margin of the shell" (Davis 2003).

Workers are also releasing fish that are artificially infested with glochidia and releasing hatchery-propagated juveniles to reintroduce *L. higginsii* into portions of its historical range and into its current range in an effort to refine these techniques (Table 1). To produce glochidia or juveniles for release, gravid females have been collected from the Hudson Essential Habitat Area in the St. Croix River or from the *L. higginsii* that were relocated to Pool 2. At Genoa National Fish Hatchery, workers remove glochidia from selected females and either place them in water containing suitable fish-hosts or pipette glochidia directly onto the gills of the fish. Workers hold the fish at the facility for approximately three weeks before releasing them in cages or as free-swimming fish (Table 1, Gordon 2002). The Hatchery typically retains some (about 5%) infested fish to monitor the success of glochidial transformation, to provide juveniles for hatchery propagation trials, and for juvenile releases (Table 1, Gordon 2002). Propagation is discussed further below under "Conservation Measures."

Essential Habitat Areas

The initial Higgins' Eye Pearlymussel Recovery Plan (USFWS 1983) listed seven locations as primary habitats (called Essential Habitat Areas in this document) and nine locations as potential secondary habitats (Table 6 - see Section IV). Essential Habitat Areas were selected based on:

1) historic and current distribution data (at the writing of the recovery plan);

2) the nature of the data available for each site, *e.g*., presence of live *L. higginsii*, presence of both sexes, presence of juveniles, numerical abundance of *L. higginsii*, etc.; and,
3) the nature of the associated fauna (*L. higginsii* has often been reported from diverse and dense mussel beds - Nelson and Freitag 1980).

The Essential Habitat Areas described in this Recovery Plan are those areas capable of supporting reproducing populations of *L. higginsii* and are of utmost importance to the conservation of the species. Cawley (1996) indicated that since 1980, all seven of the Essential Habitat Areas in the initial Higgins' Eye Pearlymussel Recovery Plan had been sampled. In addition, six of the nine secondary habitats had been sampled.

For this Revised Recovery Plan, Essential Habitat Areas are those locations where:

1. *L. higginsii* constitute at least 0.25% of the mussel community and the mussel habitat appears to be stable and supports a dense and diverse mussel community; or,

2. *L. higginsii* are found, but constitute <0.25% of the community, the mussel habitat appears to be stable and supports a dense and diverse mussel community, AND zebra mussel densities are $< 0.5/m^2$ and have not increased during the last five consecutive years[4].

For each definition, "dense and diverse" mussel communities are those that:

- include a total mussel density of $> 10/m^2$ (Upper Mississippi River) or $> 2/m^2$ (other rivers); and,
- contain at least 15 other mussel species, each at densities greater than 0.01 individual/m^2.

Each of the ten Essential Habitat Areas described in this revised recovery plan will remain as Essential Habitat Areas whether or not they meet these criteria, but any new Essential Habitat Areas must meet or exceed the criteria. Zebra mussels have severely degraded the native mussel communities at a few of the Essential Habitat Areas to the degree that they may no longer meet the definition above. These sites, however, demonstrated their importance to the conservation of *L. higginsii* until zebra mussels invaded the Upper Mississippi River in the 1990s and zebra mussels are likely the sole reason that they no longer meet the Essential Habitat criteria. Moreover, it is unclear how long zebra mussels will continue to suppress native mussel communities at these sites. Therefore, each is retained as an Essential Habitat Area until USFWS finds that data are sufficient to determine that one or more no longer possesses and is unlikely to recover the physical and biological features that are essential to the conservation of *L. higginsii*. The USFWS's Twin Cities Field Office will retain an updated list of Essential Habitat Areas for this species and should make this list available on the world wide web. Areas other

[4] For analyses of zebra mussel population dynamics, use a significance level (ζ 0#Ω#0.2 and power Ø#75 9 for all tests.

than the ten listed in this plan must meet the definitions above to qualify as Essential Habitat Areas.

Biology, Ecology and Life History

Reproduction

Major aspects of the unionid reproductive cycle have been well described. Males release sperm into the water, often in packets known as volvocoid bodies (Fuller 1974) that are taken in through the incurrent siphon by the female. Fertilization occurs and zygotes are brooded in the water tubes of the gills by the female. In the genus *Lampsilis*, the marsupia that contain the glochidia, are kidney-shaped, occupying the posterior portion of the outer gills. Female unionids can produce up to a million eggs a year (Burky 1983). The zygotes develop into larvae (glochidia) which are released into the water column in various ways. In the genus *Lampsilis,* the edge of the mantle of the female develops into a ribbon-like flap in front of the branchial opening. This flap has been described as “minnow-like” in appearance, often having a dark “eye-spot,” and thus it has been suggested to be important in attracting fish hosts (Baker 1928). The glochidia attach to a fish host, where they remain for approximately three weeks (at water temperatures of 20-22ºC - Waller, pers. comm.) as they transform to juveniles. They then drop off their fish host, develop a byssal thread, which may assist in dispersal, and upon settling on suitable habitat, use the byssal thread as a means of attachment, to prevent being swept away in water currents.

Lampsilis higginsii is a long-term brooder (bradytictic). This means that they spawn in the summer and larvae are retained in the marsupia through the winter until they are released the following spring/summer. Glochidial release has been reported during June and July (Waller and Holland-Bartels 1988) and May and September (Surber 1912). Glochidia of *L. higginsii* are morphologically similar to those of several other species of lampsilines in the Upper Mississippi River. Waller and Mitchell (1988) have shown that *Lampsilis higginsii* glochidia can be differentiated from *L. cardium, L. siliquoidea,* and *Ligumia recta* by electron microscopy; they could not be differentiated by light microscopy or morphometric measures.

Table 3 (see Section IV) identifies the known hosts for *L. higginsii.* Early studies indicated that the sauger (*Stizostedion canadense*) and freshwater drum (*Aplodinotus grunniens*) were fish hosts for glochidia of *L. higginsii* (Surber 1912; Wilson 1916; Coker *et al.* 1921). These identifications were based on examination of natural infections, but field identifications are not robust (Waller and Holland-Bartels 1988; Waller and Mitchell 1988); thus, these hosts must be questioned, although Hove and Kapuscinski (2002) have appeared to confirm sauger as a suitable host. Based on laboratory infections of fish with *L. higginsii* glochidia, Waller and Holland-Bartels (1988) indicated that four species of fish were suitable hosts: largemouth bass (*Micropterus salmoides*), smallmouth bass (*M. dolomieu*), walleye (*Stizostedion vitreum vitreum*) and yellow perch (*Perca flavescens*). There was some transformation of glochidia to juveniles on green sunfish (*Lepomis cyanellus*), whereas two species, bluegill (*Lepomis macrochirus*) and northern pike (*Esox lucius*), were considered marginal hosts, because each produced only one juvenile. The common carp (*Cyprinus carpio*) and fathead minnow (*Pimephales promelas*) were unsuitable hosts. Studies by Waller and Holland-Bartels (1988) and Waller and Mitchell (1988) supported those by Sylvester *et al.* (1984) that walleye and largemouth bass were hosts for *L. higginsii,* but Sylvester *et al*. (1984) indicated that the green sunfish and bluegill were not suitable hosts. Hove and Kapuscinski (2002) confirmed largemouth bass as suitable hosts and found that sauger and black crappie also facilitated metamorphosis of *L. higginsii* glochidia. In general, Waller and Holland-Bartels (1988) indicate that percids and centrarchids are suitable hosts, whereas cyprinids, ictalurids and catostomids are unsuitable. Neves and Widlak (1988) also indicated that members of the subfamily Lampsilinae were more likely to be found on centrarchids and percids than on cyprinids and cottids.

Feeding

Among the few published studies on unionid feeding mechanisms are recent studies by Tankersley and Dimock (1992, 1993a, 1993b) who used endoscopic techniques to examine feeding in *Pyganodon cataracta*. There have been no studies focusing specifically on *L. higginsii* but generally unionids are filter-feeders, removing small suspended food particles from the water column utilizing the large lamellibranch gills as feeding organs. Feeding rate in bivalves is known to be greatly influenced by temperature, food concentration, food particle size and body size (Jørgensen 1975; Winter 1978).

Habitat

Lampsilis higginsii has been characterized as a large river mussel species (USFWS 1983). Davis and Hart (1995) indicated that it was found in the more "riverine" portion of Pool 7 and in the tailwater reaches of other Mississippi River navigation pools. Wilcox *et al.* (1993) proposed the following decision criteria for estimating the likelihood of occurrence of *L. higginsii*:

Substrate: Substrate not firmly packed clay, flocculent silt, organic material, bedrock, concrete or unstable moving sand;

Current velocity: Current velocities less than 1 m/s during periods of low discharge;

Mussel relative abundance: If 2,000 or more mussels are sampled and no *L. higginsii* are found, then it is unlikely to be present;

Density: Density of all mussels should exceed $10/m^2$, and any rare species (including *L. higginsii*) should occur at densities greater than 0.01 individuals/m^2;

Species Richness: Species richness (number of species) should exceed 15 when as few as 250 individuals have been collected.

Additional information regarding habitat characteristics is given below.

Substrate

Strayer (1983, 1993), Vannote and Minshall (1982), and others have suggested substrate stability may be important in determining the presence of freshwater mussel communities. It is the permanence of the populations in substrate that appears to be most important in constituting a mussel "bed". At smaller spatial scales however, such as within mussel beds, substrate difference provided little predictive power (Holland-Bartels 1990; Strayer and Ralley 1993). Heath (1995) found no correlation between overall mussel density and substrate size in the Wisconsin River where *L. higginsii* was found. Hornbach *et al.* (1995) have indicated that substrate size does influence mussel density, although accounting for only a small proportion of the variability in mussel density. Mussels also apparently help to stabilize the substrate of the river in some areas (Watters 1994a).

Lampsilis higginsii has been found in various substrates from sand to boulders, but not in areas of unstable shifting coarse sands. Sylvester *et al.* (1984) found that burrowing times for *L. higginsii* were similar in clay, silt and sand, but longer in pebble-gravel substrate. *Lampsilis higginsii* were not present in rock substrate. Miller and Payne (1996b) considered substratum that was free of plants and consisted of stable, gravelly sand as suitable for *L. higginsii.* Miller and Payne (1996b) also commented on the value of wingdams for *L. higginsii*. They noted that immediately downriver of wingdams, mussel diversity was high and new species were found at a more rapid rate on the wingdam than in gravelly sand. *Lampsilis higginsii* was found immediately below the wingdam at McMillan Island and has been collected on wingdams near Prairie du Chien. Baker and Hornbach (submitted) indicated that *L. higginsii* is found in substrate that consists of coarse sand and gravel, but not in either finer (silt) or coarser (cobble) substrates. Cawley (1996) indicated that *L. higginsii* were most common in sand/gravel substrate.

Stream Flow/Current/Hydrologic Variability

DiMaio and Corkum (1995) indicated certain species of mussels may be more readily found in different hydrologic conditions. L. higginsii may be primarily adapted to large river habitats with moderate current, such as the East channel of the Mississippi River near Prairie du Chien, Wisconsin (Andrew Miller, pers. comm., U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS).

Water Quality

The effects of water quality, including inorganic and organic contaminants, are not well understood in freshwater mussels. Because of the scarcity of information in this area, most of the available data is not specific to *L. higginsii*; however, these data should provide an indication of the relative effects of various water quality measures on unionids. Although this section will not be specific to *L. higginsii*, attempts will be made to reference studies on the genus *Lampsilis* or to species in the same subfamily (Lampsilinae).

As benthic filter-feeding organisms, freshwater mussels are exposed to contaminants dissolved in water, associated with suspended particles, and deposited in bottom sediments. Thus, freshwater mussels can bioaccumulate contaminants to concentrations that greatly exceed those dissolved in water. This section is organized into two parts: (1) existing water and sediment quality at *L. higginsii* locations where reproduction is occurring and (2) water and sediment quality measures most likely to adversely affect freshwater mussels. Within each of these two sections, both traditional pollutants (*e.g.*, nitrogen, phosphorus, suspended sediment, dissolved oxygen) and inorganic and organic contaminants will be addressed.

In the Upper Mississippi River basin, sedimentation and toxic contaminants have been suggested as the major threats to biotic resources (Wiener *et al*. 1984). Surface waters in the Upper Mississippi River are hard and alkaline; toxic organic and inorganic contaminants in this system largely occur in association with suspended particles and deposited sediments. Thus, concentrations of inorganic and organic contaminants in surface waters are generally well below concentrations thought to adversely affect riverine biota. Although surface waters in the St. Croix River are softer and less alkaline than the Upper Mississippi River, this riverway has been labeled as "outstanding resource water" (Holmberg *et al*. 1997).

The majority of the available data on mussels and contaminants concerns tissue residue studies (reviewed by Havlik and Marking 1987, Naimo 1995). Although these studies document existing contaminant burdens (*e.g.*, 100 mg of cadmium per gram dry tissue weight), there is little consistency in how the samples are obtained for analysis. For example, factors such as sex, age, season, reproductive status, and feeding status can all substantially alter the results of these studies. More importantly, there is little available information on what effects these residue concentrations have on the individual. For example, information on the highest tissue residue concentration that a mussel can tolerate without an adverse biological effect (lower growth rates, poorer reproduction, etc.) is largely unknown. These types of data are usually inferred from examining residue data from heavily contaminated systems and assuming that these mussels are being adversely affected.

Water and sediment quality at locations where L. higginsii are reproducing

Long-term persistence of *L. higginsii* in the seven Essential Habitat Areas of the initial recovery plan and in the three additional Essential Habitat Areas identified in this revision is evidence of successful reproduction in these areas. Based on the presence of reproducing populations, except where severely affected by zebra mussels, water and sediment quality are presumed to be presently not adversely affecting *L. higginsii* in the Essential Habitat Areas. Due to their limited mobility, however, freshwater mussels cannot actively avoid contaminated areas. Therefore, existing conditions at a given location should not necessarily be viewed as optimal or beneficial. Rather, these data should be viewed as ranges of physico-chemical values that allow survival or reproduction of *L. higginsii* at the present time. Even though population size may be stable or even increasing at some sites, poor water or sediment quality could still be limiting population growth (*e.g.*, reproductive, juvenile survival, or growth rates could be negatively affected without causing a net population decline).

An assessment of water and sediment quality near reproducing populations of *L. higginsii* suggests that *L. higginsii* exist at locations with relatively good water and sediment quality (Tables 4 and 5 - see Section IV). It has been suggested that unionids require water with a hardness of at least 20 to 40 mg $CaCO_3$/L (Clarke and Berg 1959, Harman 1969) and an alkalinity of at least 15 mg $CaCO_3$/L (Harman 1970, Pennak 1978); hardness and alkalinity in the St. Croix and the Upper Mississippi rivers exceed these levels.

Few data exist on the concentrations of most organic contaminants and traditional pollutants thought to adversely affect freshwater mussels. Nevertheless, the presence of reproducing *L. higginsii* populations and the diversity and abundance of many other unionid species at Essential Habitat Areas, at least before zebra mussel invasions, suggests water quality is not limiting these unionid communities. Furthermore, because many inorganic and organic contaminants that enter aquatic systems associate with fine sediments (*i.e.*, silts and clays), the greatest likelihood for adverse effects from these contaminants should be in depositional areas with fine sediments.

The existing data for *L. higginsii*, however, suggests *L. higginsii* are frequently found in the more riverine portions of the Upper Mississippi River and St. Croix River and are not generally found in areas with a predominance of depositional sediments (see habitat characteristics section). Thus, *L. higginsii* are generally not located in sediments likely to have accumulated toxic concentrations of heavy metals and organic contaminants.

Water and sediment quality factors likely to affect unionids

Traditional pollutants -- The effects of traditional pollutants on freshwater mussels are virtually unknown. Suspended sediment is often cited as a factor affecting the quality of freshwater mussel habitat. Aldridge *et al*. (1987) found intermittent exposure of freshwater mussels (*Quadrula quadrula*, *Pleurobema beadleanum*, and *Fusconaia cerina*) to 600 to 750 mg/L of suspended solids adversely affected feeding rate, oxygen uptake, and excretion. Concentrations of suspended solids of this magnitude, however, are not expected to occur in either the St. Croix or Upper Mississippi Rivers; concentrations in these two rivers currently range from 1 to 54 mg/L (Table 5 - see Section IV) and from 1 to 120 mg/L (Dawson *et al*. 1984), respectively.

Un-ionized ammonia, the most studied of the traditional pollutants, is adverse to freshwater bivalves such as the fingernail clam *Musculium transversum* at concentrations as low as 30 µg NH_3/L (Sparks and Sandusky 1981), generally lower than reported for numerous other invertebrate and vertebrate species (Arthur *et al*. 1987). Concentrations of 30 µg NH_3/L are frequently observed in sediment pore water in the Upper Mississippi River during summer (Frazier *et al*. 1996).

Recently, the effects of un-ionized ammonia (NH_3) on unionids have been evaluated. Goudreau *et al*. (1993) evaluated the toxicity of NH_3 to glochidia from *Villosa iris* and observed toxicity at 284 µg NH_3/L (24 hr-LC_{50}). Although this concentration is much higher than has been shown for *Musculium*, Goudreau *et al*. (1993) used glochidia, which have been shown to be more tolerant than juveniles to some contaminants (Lasee 1991). Conversely, Wade (1992) tested 8-

day old juvenile *Utterbackia imbecillis* and found toxicity at 153 µg NH_3/L--which is less than one-half the national one-hour average criterion of 260 µg NH_3/L at 20 C° and a pH of 8.0 (U.S. EPA 1985). These studies suggest that more information on the sensitivity of the various life history stages is needed.

Because concentrations of NH_3 are related to temperature and pH, elevated concentrations can occur in riverine systems during low flow periods. However, concentrations of NH_3 are also related to particle size, with finer sediments containing elevated concentrations of NH_3 (Frazier *et al*. 1996). Thus, the greatest threat to unionids from NH_3 is likely to occur in fine sediments during low flow periods.

Inorganic and Organic Contaminants -- An assessment of the available data in the Upper Mississippi River basin suggests contamination of riverine sediments with elevated concentrations of heavy metals (Cd, Cu, Hg, and Zn), polychlorinated biphenyls (PCBs), and ammonia may pose the greatest harm to benthic invertebrates (Naimo *et al*. 1992a, 1992b, Steingraeber *et al*. 1994, Frazier *et al*. 1996). Few data exist on the effects of newer pesticides on freshwater mussels because, in part, their short half-life in biological systems (hours or days compared to years for many metals) makes their presence difficult to quantify.

Many contaminants, particularly toxic metals, that enter aquatic systems are adsorbed onto suspended particles and subsequently accumulate in surficial sediments (Tessier and Campbell 1987). Toxic concentrations of dissolved metals are uncommon in oxic surface waters. In the Mississippi River, for example, more than 90% of the trace metal load is associated with particles (Trefry *et al*. 1986). Thus, these metals can be accumulated by, and directly affect, filter-feeding benthic organisms such as freshwater mussels. Recently, studies have focused on sediment pore water because it is well known that concentrations of inorganic and organic contaminants in pore water can greatly exceed concentrations in overlying surface water. Yeager *et al.* (1994) demonstrated that although juvenile *Villosa iris* burrowed less than 1 cm into the sediment, they were not exposed to the overlying water. Thus, although freshwater mussels, in general, can be exposed to metals dissolved in water, associated with suspended particles, and deposited in bottom sediments, juvenile mussels are most likely exposed to elevated metal concentrations found in association with sediment or pore water.

The effects of heavy metals on freshwater mussels, particularly cadmium (Cd), copper (Cu), mercury (Hg), and zinc (Zn), have been studied more than other contaminants because they are widespread, persistent, potentially toxic, and because many freshwater ecosystems are contaminated with these metals, as a result of human activities (Naimo 1995). Laboratory-based acute toxicity values for juvenile mussels, range from 44-388 µg Cu/L (Keller and Zam 1991, Jacobson *et al*. 1993), 211-588 µg Zn/L (Keller and Zam 1991, McCann 1993), 107-345 µg Cd/L (Keller and Zam 1991, Lasee 1991). It should be noted that concentrations of total Cd, Cu, Hg, and Zn in surface waters of the St. Croix River at St. Croix Falls, Wisconsin, are well below concentrations thought to be harmful to freshwater mussels (Table 5 - see Section IV). Similarly, in the reach of the Upper Mississippi River between Coon Rapids, Minnesota (River Mile 870) and Red Wing, Minnesota (River Mile 800), concentrations of total Cd, Cu, and Zn in surface waters are also below concentrations thought to be detrimental to mussels (ranges, Cd: 0.8-2.0 µg/L, Cu: 5.2-6.8 µg/L, and Zn: 20-30 µg/L; Boyer 1984).

Virtually nothing is known about the sublethal impacts in mussels to long-term exposure to metals at low concentration. Although laboratory toxicity tests provide tolerance limits, few of these tests have used environmentally realistic exposure concentrations. For example, total concentrations of Cd, Cu, Hg, and Zn in many oxic surface waters are in the ng/L range, yet many toxicity studies have exposed mussels to concentrations in the µg/L or even mg/L range (reviewed in Naimo 1995). Sublethal effects are frequently observed at concentrations only one-half the lethal concentrations, which indicates freshwater mussels become stressed at metal concentrations much lower than those reported in acute toxicity tests. For example, Jacobson *et al*. (1993) determined the 24-h LC_{50} for juvenile *Villosa iris* was 83 µg Cu/L, but the 24-h EC_{50} (percent gaped and dead or ungaped) was 27 µg Cu/L. In addition, Lasee (1991) determined that 0-d old juvenile *Lampsilis cardium* were killed at concentrations of 141 µg Cd/L, but significant reductions in ciliary activity, a surrogate for feeding intensity, were evident at concentrations of 90 µg Cd/L.

Comparatively less is known about both acute and sublethal effects of organic contaminants on freshwater mussels. Keller (1993) exposed juvenile *Utterbackia imbecillis* to eight organic compounds in laboratory tests and found pentachlorophenol was the most toxic (48-h LC_{50} = 0.6 mg/L) and methanol (48-h LC_{50} = 37.0 mg/L) was the least toxic. Mussels were insensitive to the herbicide Hydrothol-191 (96-h LC_{50} = 4.9 mg/L) and two chlorinated pesticides (chlordane, 96-h LC_{50} = 0.9 mg/L and toxaphene, 96-h LC_{50} = 0.7 mg/L), relative to *Ceriodaphnia dubia*, an organism commonly tested in laboratory studies (Keller 1993). Furthermore, juvenile *Utterbackia imbecillis* and *Villosa villosa* were insensitive to malathion, a commonly used organophosphorus insecticide (Keller and Ruessler 1997).

Although there are fewer data on the effects of organic contaminants to unionid mussels, the available data suggest some compounds in the Upper Mississippi River have the potential to harm *L. higginsii* and to degrade entire benthic invertebrate communities. For example, zebra mussels have been shown to bioaccumulate substantial quantities of PCBs in the Upper Mississippi River (M.R. Bartsch, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, pers. comm.). In addition, a survey of PCBs in emergent mayflies identified two zones of concern regarding PCB contamination of riverine sediments--Pools 2 through 6 and Pool 15 of the Upper Mississippi River (Steingraeber *et al*. 1994). The Sylvan Slough Essential Habitat Area is in Pool 15, and further study is recommended.

In the Mississippi River, suspended sediments can transport substantial quantities of organochlorine pesticides such as PCBs, DDT and its metabolites (DDE and DDD), aldrin, and dieldrin. For example, during 1988 to 1993, suspended sediments in the Mississippi River transported between 410 and 37,000 grams per day of total PCBs (Rostad 1997). Because unionids can filter large volumes of water (range, 60 to 490 mL/individual/hour; Stanczykowska *et al.* 1976), the potential exists for unionids to obtain a substantial contaminant mass through inhalation of suspended particles.

Contaminants may also affect mussels via the fish that serve as hosts for the juveniles. Recently, it has been shown that exposure to fish containing elevated body burdens of DDE, toxaphene, or atrazine during transformation reduced the survival of juvenile mussels (N. J. Kernaghan, Florida Caribbean Science Center, Gainesville, Florida, pers. comm.). Thus, studies on *L. higginsii* should also examine contaminant body burdens in their fish hosts.

Water Quality Data Gaps

1. The vast majority of literature addressing contaminant effects on freshwater mussels involves tissue residue studies. The biological effects of these contaminant residues on freshwater mussels typically are unknown (*i.e.*, can a mussel accumulate 100 mg/g of contaminant "X" without deleterious effects to reproduction, feeding, and survival?).

2. One serious constraint in evaluating the effects of contaminants on the various life stages of freshwater mussels is the lack of basic information required for laboratory toxicity studies: nutritional requirements, culture methods, and realistic exposure concentrations--all of these likely affect the susceptibility of mussels to contaminant exposure. Furthermore, the lack of data on nutritional requirements and culture methods for species at risk, such as *L. higginsii*, jeopardizes species-specific studies.

3. Comparative data on modes of uptake in freshwater mussels are needed to more fully evaluate contaminant effects, design contaminant monitoring programs, and to develop water-quality criteria that adequately protect freshwater mussels. The relative significance of contaminant uptake from food sources, surface water, pore water, and sediments as routes of exposure is not documented.

4. The existing data on the most sensitive life history stage (*i.e.*, glochidium, juvenile, adult) are conflicting. More information is needed to determine which life history stage and sex is the most sensitive or to determine if this sensitivity is contaminant-specific. These data will help guide and standardize field and laboratory toxicity tests for unionids.

Community Associations

Lampsilis higginsii is often found with other mussels. Many researchers have commented that this species is most often found in dense and diverse mussel beds. Cawley's (1996) review indicated that on average 20.7 species of mussels were found at sites where *L. higginsii* have been collected (range 2 - 36 species). Havlik (1983) commented on the common occurrence of *L. higginsii* with either *Obovaria olivaria* or *Megalonaias nervosa*. Duncan and Thiel (1983) and Davis and Hart (1995) also reported a close relationship between the presence of *O. olivaria* and *L. higginsii*. Miller and Payne (1996b), however, found no positive relationship between the presence of *M. nervosa* and *L. higginsii*. Heath (1995) noted that four species (*Amblema plicata*, *Quadrula pustulosa*, *Fusconaia flava* and *L. cardium*) are very common at all known *L. higginsii* sites. Others have reported that at most *L. higginsii* sites, *L. higginsii* accounted for approximately 0.5% of the community (Fuller 1980; Thiel 1981; Holland-Bartels 1990; Miller and Payne 1991, 1992, 1993, 1994; Hornbach *et al*. 1995; Miller and Payne 1995a, 1995b, 1996a, 1997). In some areas *L. higginsii* may account for up to approximately 2.75% of the community (Miller *unpubl. data*), whereas in some marginal areas it may make up a smaller proportion of the mussel community. Hornbach *et al.* (1995) hypothesized that populations in marginal habitat areas are maintained by fish-mediated transport of glochidia from other populations.

Non-human Predators

The natural predators of adult mussels include a variety of aquatic and semi-aquatic animals: *Ondatra zibethicus* (muskrats) (Apgar 1887; Evermann and Clark 1920; Van Cleave 1940; Errington 1941; Takos 1947; Pennak 1978; Hanson *et al*. 1989; Convey *et al*. 1989; Neves and Odom 1989; Lacki *et al*. 1990), *Lutra canadensis* (river otters) (Morejohn 1969; Toweill 1974; Pennak 1978), *Mephitis mephitis* (striped skunk) (Hazard 1982), *Mustela vison* (mink) (Pennak 1978), turtles (Pennak 1978), *Cryptobranchus* (hell benders) (Pennak 1978), fish (McMahon 1991; Williams *et al*. 1993) and *Procyon lotor* (raccoon) (Evermann and Clark 1920; Hazard 1982). Tyrrell and Hornbach (1998) found differences in the sizes of mussels taken from the middens and adjacent river samples indicating that small mammals are size-specific mussel predators in the St. Croix and Mississippi Rivers. Their conclusions are supported by previous findings in similar studies. Convey *et al*. (1989), Hanson *et al*. (1989) and Jokela and Mutikainen (1995) found that mussels in midden piles were longer on average, than the mussel population in the adjoining body of water. Tyrrell and Hornbach (1998) also found differences in species composition, richness and diversity between mussels collected from middens and adjacent river sites, revealing species-specific selection by small mammal predators. This result was supported by the findings of Neves and Odom (1989) and Watters (1995), who found that muskrats exhibited preferences for some mussel species over others. Davis and Hart (1995) found 2 freshly consumed *L. higginsii*, both females, in muskrat middens in Pool 7 of the Mississippi River.

If populations of *L. higginsii* continue to decline in the mainstem of the Mississippi River, it is possible that predation, especially in smaller river systems such as the St. Croix and Wisconsin rivers may become a more important threat to *L. higginsii*.

Critical Habitat Designation

If following completion of this plan, we find that it is prudent and determinable to designate critical habitat for this species, the Service will prepare a critical habitat proposal at such time as our available resources and other listing priorities under the Act allow. This proposal will be based on the essential habitat features needed to ensure the conservation and recovery of the species, many of which have been documented in the Habitat section of this Recovery Plan.

Genetics

There have been relatively few studies that address the genetic structure and diversity of unionid populations. Many of the studies that have been conducted have been structured to examine evolutionary relationships among species (*e.g.* Davis and Fuller, 1981; Davis *et al.* 1981; Davis 1984; Lydeard *et al.* 1996). Kat (1983) and Stiven and Alderman (1992) focused their studies on *Lampsilis* species, but neither included *L. higginsii*. As in most genetic studies on unionids, these studies focused on species and subspecies identification - *i.e.*,determining the "status" of various taxonomic groups. Few studies have been designed to examine the degree of genetic variability both among and within populations of unionids. These types of studies are imperative if conservation efforts, including relocation projects, are to be successful in maintaining the genetic diversity of mussel species (Villella *et al.*, 1997). One study by Berg *et al.* (1997) indicated that large river species and small stream species may differ in their "within" and "among"-population genetic variability. A large river species was found to have a high level of within-population genetic variability and a low level of among-population variability. Berg *et al.* (1997) claimed that large river populations may be considered a single large metapopulation, and thus preservation of several populations in big rivers will conserve most of a taxon's genetic diversity. While their study is intriguing, it is based on only a single species of mussel (*Quadrula quadrula*).

Data from mitochondrial DNA analysis from four populations of *L. higginsii* in the St. Croix (Hudson) and Mississippi Rivers [Whiskey Rock (IA), Cassville, WI, and Cordova, IL] indicate a high degree of genetic variability within populations with no site-specific haplotypes (Bonnie Bowen, Dept. Animal Ecology, Iowa State University, Ames, Iowa *in litt.* 1999, 2002, and 2003). *L. higginsii* seems to possess a high degree of genetic variability relative to other endangered species (B. Bowen *in litt.* 2002 and 2003). Biologists planning and implementing artificial propagation and reintroduction of *L. higginsii* must be careful to ensure that reintroduced populations reflect the genetic variability found in natural populations.

Reasons for listing

The major reasons for listing *L. higginsii* were the decrease in both abundance and range of the species. As stated in the initial recovery plan (USFWS 1983), the Higgins' eye pearlymussel was never abundant and Coker (1919) indicated that it was becoming increasingly rare even at the end of the 1800s. The fact that there were few records of live specimens from the early 1900s until the enactment of the Endangered Species Act in 1973 was a major factor in its listing in 1976.

Since the initial listing of the species, a variety of authors have noted declines in mussel populations within the range of *L. higginsii.* Thiel (1987) reported mid-1980's die-offs of mussels in the Mississippi River that were most noticeable in areas of *L. higginsii* occurrence. Blodgett and Sparks (1987a) noted a decline in the unionid community near the Sylvan Slough Essential Habitat Area, and Havlik (1987) noted a die-off near Prairie du Chien, Wisconsin, another Essential Habitat Area. Havlik also indicated an "unusual" number of fresh-dead *L.*

higginsii at this site in 1985. Few papers presented at a workshop examining die-offs (Neves 1987) gave concrete reasons for the cause of the die-off, however Scholla *et al.* (1987) indicated that a gram-negative rod bacterium, which forms yellow colonies was associated with "sick" mussels from the Tennessee River. Research on mussel pathogens (bacterial, viral and protozoan) and their effects on population levels has not been conducted.

<u>Present Threats</u>

Zebra Mussels (see Tasks under 1.1 and 2.3 in the step-down outline)

The introduction of the zebra mussel to North America has negatively affected populations of native mussels (Unionidae) (Mackie 1991; Hunter and Bailey 1992; Strayer 1999). Unionid mussels evolved in the absence of any major fouling organisms and have no mechanisms for dealing with deleterious effects of epibionts. Zebra mussels have the potential to impact unionids both directly, by actual attachment, and indirectly, through competition for food. The relative amount of stress caused by zebra mussel attachment may be species and sex specific. For example, members of the subfamily Ambleminae, which are short-term brooders, are less stressed by zebra mussel colonization than are long-term brooders, such as the Lampsilinae (Haag *et al*. 1993). Sexual differences within a species also exist, with colonized males being less stressed than colonized females (Haag *et al*. 1993). These studies suggest that zebra mussel introduction could drastically alter unionid mussel community structure and overall biodiversity by affecting the fitness of community members unequally.

One way that zebra mussels effect unionids is through direct attachment to their shells. Zebra mussels can colonize all species and may reduce both population size and species richness of unionids (Mackie 1991). Observations by Hebert *et al*. (1989) and laboratory studies by Lewandowski (1976) showed that zebra mussel attachment rates were higher on live unionids than on dead unionids or rocks, although recent studies by Toczylowski and Hunter (1996) indicated that this preference may not be exhibited in the field. In 1989, on Great Lake gravel substrates, one third of the zebra mussels were attached to unionids, while the rest were attached to the gravel (Hebert *et al*. 1989). Unionid shells may provide substrate for zebra mussels in areas that they would otherwise be unable to colonize. Hebert *et al*. (1989) note that zebra mussels are most often found in locations with gravel substrate, but can also be found on sand and silt substrate if hard objects, such as unionids, are available. In the Great Lakes and in Polish lakes, up to 90% of the unionid population had attached zebra mussels (Lewandowski 1976; Hebert *et al*. 1989). Haag *et al*. (1993) examined unionids in Lake Erie and found an average of 216 zebra mussels attached to each unionid. Individual unionids have been found encrusted with over 10,000 zebra mussels (Hebert *et al*. 1991).

The direct attachment of zebra mussels may affect unionids in several ways. Unionid locomotion may be impaired by the attached zebra mussel biomass. Zebra mussel biomass often exceeds that of the underlying host unionid (Lewandowski 1976, Mackie 1991). Tucker (1994) indicated that habitat alteration, with zebra mussels forming a "pavement" over gravel bars, prevented unionids from burrowing. Zebra mussels may interfere with siphon extension or prevent valve closure and opening, resulting in inhibition of feeding, respiration or excretion. Wiktor (1963) reported that zebra mussels can over-grow *Unio spp*. and *Anodonta spp.*, resulting in “suffocation." Prevention of valve closure may increase the susceptibility of unionids to diseases, parasites, and predation. Zebra mussels can also cause shell deformation of unionid shells, especially near the siphons (Lewandowski 1976). These deformations may also contribute to inhibition of physiological functions.

Indirect effects of zebra mussels on unionids include potential competition for food. Zebra mussels, as filter-feeding organisms, have the potential to strip the water of food and nutrients. The enormous influence of zebra mussels on the phytoplankton dynamics of aquatic systems has been estimated by a number of authors. Stanczykowska *et al*. (1976) calculated that filter feeders, especially zebra mussels, consumed 8% of the primary production per year in a Polish lake. Lewandowski (1983) concluded that a population of zebra mussels in another lake in Poland can filter 213×10^6 m^3 of water per year. Reeders *et al*. (1989) indicated that the zebra mussel populations in Lakes Ijsselmeer and Markermeer in the Netherlands had the capacity to filter these lakes once or twice a month, greatly reducing phytoplankton biomass.

Zebra mussels may also be affecting unionid mussel populations by filtering their glochidia. MacIsaac *et al.* (1991) indicated that although mussels preferred algal foods smaller than 50 µm, they can ingest particles at least up to 400 µm in length. McMahon (1991) indicated that unionid glochidia range in size from 50-400 µm, with most less than 200 um. Consequently, it is possible that zebra mussels could consume unionid glochidia.

There are no studies that adequately quantify competition for food among freshwater mussels. Based on theoretical considerations, Levinton (1972) claimed it unlikely that there is competition for food among filter-feeding organisms. A number of studies in marine systems (*e.g*. Wildish and Kristmanson 1984, Fréchette *et al*. 1989), however, indicate that food supply to bivalves may be limited and that competition for food may be an important factor in controlling bivalve growth. Certainly, the potential for competition for food resources between zebra mussels and unionids is great. Strayer et *al.* (1996) and Caraco *et al.* (1997) have implicated a reduction of phytoplankton abundance in the Hudson River to the introduction of zebra mussels to this system; this may also explain subsequent reductions in unionid density, even though the number of zebra mussels attached per unionid is quite low.

Zebra mussels have clearly had major impacts on North American unionids (Strayer 1999). Strayer and Smith (1996) have shown that unionid density fell by 56%, recruitment of young-of-the-year unionids fell by 90%, and condition of unionids fell by 20-50%, 4 years after the introduction of zebra mussels into the Hudson River. Similarly, Ricciardi *et al.* (1996) found significant declines in unionid density and physiological condition in the St. Lawrence River 3-5 years after the introduction of zebra mussels.

All current populations of *Lampsilis higginsii* are under the potential threat of being colonized by zebra mussels; only one of the current Essential Habitat Areas, Interstate Park in the St. Croix River, is entirely free of zebra mussels. Tucker *et al.* (1993) reported the widespread colonization of unionids by zebra mussels in the upper Mississippi River. Clarke and Loter (1995) found nearly a ten-fold increase in zebra mussel densities from 1993 to 1994 at Prairie du Chien. They predicted that by 1996, zebra mussels could have significant impacts on unionids, including *L. higginsii*. Beckett *et al.* (1997) also found large increases in zebra mussel density at Prairie du Chien, but noted that in other areas (Pools 9 and 11), zebra mussel densities were still fairly low. Cope *et al.* (1996) summarized the status of zebra mussels in the upper Mississippi River and indicated that densities ranged from 1-11,000 zebra mussels/m^2 on the locks and dams in this stretch of the river. Ricciardi *et al.* (1995b) indicated that severe unionid mortality (>90%) is expected when zebra mussel density reach 6000/m^2 with infestation rates of 100 zebra mussels/unionid.

Zebra mussels are having a substantial impact on the mussel community at Prairie du Chien, WI, one of the Essential Habitat Areas (Miller and Payne 2001). Quantitative and qualitative samples for freshwater bivalves have been collected in the east channel of the Mississippi River at Prairie du Chien by personnel of the U.S. Army Engineer Waterways Experiment Station since 1984 (Miller, pers. comm.). The first zebra mussels in quantitative samples were taken in 1993, averaging 2 individuals/m^2. Zebra mussel density increased to over 10,000 individuals/m^2 in 1996. Although zebra mussel densities decreased and varied from 1996 to 2000, mean density estimates typically exceeded 1,000 individuals/m^2. Coincident with these densities of live zebra mussels, shell material from dead zebra mussels had increased to a depth of approximately 50 cm in some areas. Additionally, divers reported substantial hydrogen sulfide production associated with dead zebra mussels and other organic debris.

For the first 10 years (from 1984 to 1994), evidence of recent recruitment for native mussels in the East Channel was highly variable and obviously unaffected by zebra mussels (Miller, *unpubl. data*). For example, the percentage of live unionids less than 30 mm total shell length during this period varied from 10.7% in 1984 to a maximum of 41.5% in 1993. The percentage of species showing at least some evidence of recent recruitment ranged from a low of 36.8% in 1992 to a high of 75% in 1987. In 1996, when zebra mussel density was at its maximum, there were still juvenile native mussels present. However, the percentage of recent native mussel recruits, both species and individuals, decreased to 0.0% in 1999 and 2000. Thus, zebra mussel densities in 1996 and 1997 virtually eliminated recruitment of native species by 1999.

Mean density of all unionids in the East Channel varied from a maximum of 149 individuals/m^2 to a minimum of 28.3 individuals/m^2 in the first 10 years (1984-1994, Miller, *unpubl. data*). Year-to-year variation could have been caused by slight differences in sample site locations, mortality of older age classes, and variation in recruitment. The rapid decline in native mussel density after 1996, first noted in 1998 (10.1 individuals/m^2) and continuing in 1999 (1.7 individuals/m^2), however, is almost certainly related to the presence of zebra mussels. Before 1999 *L. higginsii* comprised ∅8+ of the total native mussel fauna in the East Channel in all study years. Live specimens of *L. higginsii* were not collected at this location during quantitative (*i.e.*, systematic, randomized) sampling in 1999 and 2000, however, and only one live *L. higginsii* was collected during qualitative sampling in those two years. In 1999, quantitative and qualitative samples were also collected in the main channel of the Mississippi River approximately 1 mile from the sampling location in the East Channel. A qualitative sample collected there included five *L. higginsii* out of a total of 198 unionids collected (*i.e.*, *L. higginsii* comprised 2.5% of the sample). Zebra mussel densities were lower in this main channel location than in the East Channel.

In the long term, zebra mussels may have only transitory or temporarily depressing impacts on native mussel populations, including those of *L. higginsii.* The current data indicate, however, that it is prudent to consider zebra mussels as a mortal threat to *L. higginsii* until new information indicates otherwise (*e.g.*, data indicating recovery of *L. higginsii* populations affected by zebra mussels).

Humans agents (*e.g.*, barges and recreational boats) are likely the most important and, perhaps, the only way by which zebra mussels spread upstream in rivers (Carlton 1993). Zebra mussel veligers and adults cling to nearly anything submerged and can survive for days out of water. Recreational and commercial vessels transport zebra mussels when they attach to exterior hulls or other structures or when they inhabit bilges, bait wells, water intake fittings, or any other wetted part of boats. They can be spread by any wetted equipment, such as construction equipment previously used in infested water or by diving equipment, including air tanks and dive suits used in infested waters.

Due to the presence of a veliger larvae in the life-cycle of zebra mussels, downstream transport is common in river populations. In Europe's Rhine River, studies indicate that upstream lakes and impounded reaches along the river provide the veligers necessary to maintain downstream populations of *Dreissena polymorpha* (Borcherding and De Ruyter Van Steveninck, 1992; Janz and Neumann, 1992; Kern *et al.*, 1994). Kern *et al.* (1994) indicate that zebra mussel population fluctuations in upstream lakes (mainly caused by waterfowl - Cleven and Frenzel, 1993) were responsible for downstream fluctuations in population levels. Clarke (1992), Carlton (1993) and Martel (1995), among others, have indicated that upstream dispersal of zebra mussels is due to human transport, primarily on boats. Although overland transport on small, trailered boats may be a mechanism for upstream dispersal (Ricciardi *et al.,* 1995a), the majority of within-river upstream transport occurs by attachment to commercial and recreational boats.

Without upstream transport and a stable upstream population of zebra mussels, it is not clear whether downstream populations will remain stable. Whitney *et al.* (1995) reported drastic declines in zebra mussels in the Illinois River after large populations were reported in 1994. It is presumed that transport of zebra mussels from the Great Lakes through the Illinois River, with subsequent upstream transport on commercial barges, resulted in the current distribution of zebra mussels in the Mississippi River from St. Paul, MN and downstream. Whitney *et al.* (1995) indicate "Given the man-made connection with Lake Michigan ... we expect mussels numbers in the Illinois will fluctuate dramatically over the next few years ..."

There are large populations of zebra mussels as far upstream as Lake Pepin on the Mississippi River (Pool 4). Zebra mussels have been found farther upstream at locks and dams as far as St. Paul, MN, but self-sustaining populations upstream of Pool 4 may not exist at this time, due to a lack of a significant upstream source of veligers. In the St. Croix River, however, zebra mussel populations are recently established and appear to be self-sustaining and growing in the mostly lacustrine portion of the lower river, upstream to Stillwater, MN (N. Rowse, USFWS, Bloomington, MN, pers. comm. 2003); this reach of the St. Croix River includes both the Hudson and Prescott Essential Habitat Areas.

Currently, there is a proposal to develop an invasive species barrier between Lake Michigan and the Illinois River (Moy 1999), although at present the design would not restrict zebra mussels. The only hope of developing effective strategies for managing zebra mussels, or of determining if specific strategies are necessary or feasible, is to monitor the spread of zebra mussels and their potential effects on *L. higginsii*, particularly in Essential Habitat Areas.

On 15 May 2000, the USFWS issued a biological opinion to the U.S. Army Corps of Engineers (Corps) in which they determined that the Corps' continued operation and maintenance of the 9-foot navigation channel on the Upper Mississippi River System (UMRS) would jeopardize the continued existence of *Lampsilis higginsii*. USFWS based this finding on the effects to *L. higginsii* of the upriver transport of zebra mussels by commercial and recreational vessels. In its biological opinion, the USFWS provided a reasonable and prudent alternative to the proposed action to avoid jeopardizing *L. higginsii.* It also provided the Corps' with reasonable and prudent measures to minimize the impact of incidental take that would result from implementation of the proposed action. Implementation of the reasonable and prudent alternative and the reasonable and prudent measures is mandatory for the Corps. As a result, the Corps must (1) conduct a *L. higginsii* relocation feasibility analysis, (2) prepare a Higgins' eye Pearlymussel Relocation Plan, (3) implement a monitoring program for *L. higginsii* and other unionids in the Upper Mississippi River System, (4) investigate opportunities to protect live *L. higginsii* individuals within essential habitat areas in the Upper Mississippi River System during the interim period between issuance of the biological opinion and implementation of the relocation phase, and (5) develop and implement an action plan to monitor abundance and distribution of zebra mussels on the Upper Mississippi River System.

In response to the biological opinion, the U.S. Army Corps of Engineers established a Mussel Coordination Team with a Partnership Agreement signed by agency heads of the U.S. Army Corps of Engineers, St. Paul and Rock Island Districts; the USFWS; the U.S. Geological Survey; the National Park Service; the U.S. Coast Guard; and the departments of natural resources from the states of Minnesota, Wisconsin, Iowa and Illinois. The purpose of the Mussel Coordination Team is to work cooperatively to coordinate and plan relevant mussel studies and projects and to share information on the management of native mussel resources and control of invasive non-indigenous mussel species.

The Corps subsequently developed draft interim and long-term goals and objectives to address the conservation of *L. higginsii* (U.S. Army Corps of Engineers 2002). The Interim Goal (next 10 years) is to maintain and/or establish reproductively viable populations of Higgins' Eye Pearlymussels based on the following objectives:

Objective 1. Maintain viable populations of *L. higginsii* and other native mussels at the Interstate, Hudson, Prescott and Orion Essential Habitat Areas.

Objective 2. Protect as many *L. higginsii* as practical in the following Essential Habitat Areas and/or other important habitats: Lower St. Croix River (Hudson), Lower St. Croix River (Prescott), UMR - Pool 9 (Whiskey Rock), UMR - Pool 10 (Harpers Slough), UMR - Pool 10 (Prairie du Chien), UMR - Pool 10 (McMillan Island), UMR – Pool 13 (Bellevue), UMR - Pool 14 (Cordova), UMR - Pool 15 (Sylvan Slough).

Objective 3. Establish a minimum of five new and viable populations of *L. higginsii* in the UMR and/or tributaries un-infested or with low level infestations of zebra mussels.

Objective 4. Monitor trends in abundance and distribution of *L. higginsii* and other native mussels.

Objective 5. Monitor trends in abundance and distribution of zebra mussels in the UMRS.

The Long-term Goal of the Corps' conservation plan is to maintain existing (year 2000) population levels of Higgins' eye pearlymussels within at least four geographically separate areas meeting the criteria for Essential Habitat.

Objective 1. Prevent zebra mussel infestation above Lake Pepin and into the Lower Wisconsin River and other UMRS tributaries and reverse current zebra mussel population trends in the UMRS, especially from Lake Pepin downstream to the confluence of the Illinois River.

Objective 2. Restore *L. higginsii* populations and habitat in essential and other habitat areas.

Various aspects of these plans were initiated in summer 2001. Higgins' eye pearlymussel and zebra mussel populations will be monitored at Essential Habitat Areas and at other key study sites over the next 10-25 years to evaluate the effectiveness of past and current management strategies.

Currently, the areas above Pool 4 include areas of historic *L. higginsii* populations as well as two Essential Habitat Areas (both in the St. Croix River). Invasion of those two areas could result in the relocation of *L. higginsii* to river reaches where zebra mussels are absent or present at low densities. Relocation of *L. higginsii* to uninfested rivers or other waters may become the only means of preserving the species. Thus, there is need for (1) capability to identify suitable *L. higginsii* habitat refuge areas, (2) measures to safely and effectively remove all life stages of zebra mussels from *L. higginsii* to be relocated to avoid contaminating release sites, and (3) safe and effective *L. higginsii* relocation methods and protocols.

The Team, therefore, stresses the importance of:

1. Preventing zebra mussels from spreading to the remaining uninfested *L. higginsii* areas in the St. Croix and Wisconsin rivers.

2. Monitoring, studying, and documenting zebra mussels and their impacts on *L. higginsii*, particularly in infested Essential Habitat Areas.

3. Researching and developing *L. higginsii* habitat identification guidelines for selecting refuge areas outside present *L. higginsii* range.

4. Developing *L. higginsii* relocation techniques.

Habitat Alteration (see Tasks under 1.2, 1.3, 1.4, 1.8, and 2.1 in the step-down outline)

Modifications to the Upper Mississippi River (UMR) for navigation began about 1878 when Congress authorized a 4 ½-foot navigation channel. Modifications consisted primarily of clearing and snagging, construction of wing and closing dams, and a canal to bypass the Des Moines rapids at Keokuk, Iowa. In 1907, a 6-foot channel was authorized, with construction of more wing and closing dams, dredging, bank revetment, and two locks at the Rock Island rapids, Illinois. In 1930, a 9-foot channel was authorized, including the construction of locks and dams, and was completed by 1940 (Crittenden 1980). These modifications have resulted in profound changes in the nature of the river, primarily replacing a free-flowing alluvial system with a stepped gradient river. Continual maintenance of the 9-foot channel requires dredging, wing and closing dam reconstruction, and bank stabilization. The last major modification on the UMRS occurred in 1995 when a second lock at Melvin Price Locks and Dam (Alton, Illinois) became operational, theoretically increasing the capacity of the lock and dam system to pass tow traffic upriver.

Although the immediate result of lock and dam construction was an increase in the volume of backwater lakes and sloughs, over time an equilibrium between flow and cross-section was restored by an increase in sedimentation rates in these new navigation pools. Substrate stability is of paramount importance in maintaining mussel populations (Vannote and Minshall 1982; Strayer 1983, 1993). Therefore, changes in substrate composition are likely to have important impacts on mussel communities. Siltation rates in pools 7, 8 and 9 have been estimated at approximately 0.7-2.9 cm/year (LePage *et al.* 1980). In addition, there has been an increase in sediment deposition in Lake Pepin (Pool 4) since the early 1900s, leading to a shift from a coarse gravel mixed with mud to one dominated by silt (Thiel 1981). However, much of this sedimentation has taken place in backwaters rather than in main channel and main channel border habitats where *L. higginsii* is typically found.

These changes have undoubtedly influenced, and continue to influence, mussel habitat. Fuller (1980), Havlik (1983), Hornbach *et al*. (1992) and Thiel (1981) have all shown that there has been a decline in the mussel species richness found in the Upper Mississippi River, compared to species richness found in pre-impoundment studies by Ellis (1931a,b). However, since *L. higginsii* has apparently always been a relatively minor component of the mussel community

(USFWS 1983) a direct link between changes in the distribution and abundance of this species and habitat alteration is difficult to ascertain.

In 1987, the Corps of Engineers consulted with the USFWS on the effects of increased tow traffic on *L. higginsii* due to the proposed construction of the second lock at the Melvin Price Locks and Dam. The resulting biological opinion and incidental take statement required the Corps to conduct a baseline and navigation effects study of four mussel beds on the UMRS (USFWS 1987). Miller *et al.* (1990) designed and initiated the study in 1988. They indicated that evidence of negative effects of commercial traffic on mussels and *L. higginsii* would be assessed using the following six parameters: 1) decrease in the density of five common-to-abundant species, 2) absence of *L. higginsii*, 3) decrease in live-to-recently-dead ratios for dominant species, 4) loss of more than 25 percent of the mussel species, 5) no evidence of recent recruitment and, 6) significant reduction in growth rates or increase in mortality. These constituted triggering mechanisms, any one of which would necessitate the reinitiation of consultation with the Corps of Engineers to reassess the impacts of tow traffic on the species. The baseline phase of this study has been completed (Miller and Payne 1991, 1992, 1993, 1994, 1995a,1995b, 1996a, 1997) and is now in the monitoring phase. In the year 2004, the two agencies will meet and reevaluate the necessity of monitoring beyond that date.

Miller and Payne (1996a) noted that, at no time, could velocity changes from a single or multiple tow passage be considered damaging to benthic organisms or their habitat. Furthermore, they state that tow-induced changes in turbidity and suspended solids at mussel beds in the UMR were minor, of short duration and likely to have only minimal effects (Miller and Payne 1996a). Studies from 1990 to 1994 by Clarke and Loter (1995) on *L. higginsii* populations at Prairie du Chien, indicated that barge traffic did not damage mussels at any site and that no significant changes in the numbers of *L. higginsii* occurred at any sites. They also found that condition indices of a common species (*Amblema plicata*) did not change. Clarke and Loter (1995) did find some changes in the number of mussel species, increases at some sites and decreases at others, which they attributed to the Great Flood of 1993 and not to barge traffic. However, as tow traffic is projected to increase on the UMRS in future years, it is essential that monitoring of these potential effects be continued.

Much of the habitat alterations due to navigation since the late 1800s, including the 4-foot, 6-foot, and 9-foot channel projects, and operation and maintenance of the navigation system, have already occurred. The Corps, in cooperation with USFWS and other agencies, work to ensure that ongoing maintenance activities, such as dredging and disposal, are implemented to avoid *L. higginsii* habitat. However, future habitat alterations associated with navigation and increasing tow traffic over the next 50 years may adversely affect the species. These impacts are the subject of two current Endangered Species Act Section 7 consultations with the Corps of Engineers on the operation and maintenance of the 9-foot channel project (see above) and system-wide navigation improvements.

The Corps of Engineers indicated that, in their best professional judgement, a 220 percent increase in barge traffic in specific areas of the East channel at Prairie du Chien could result in up to a 20 percent reduction in the number of *L. higginsii* as a result of chronic perturbations over a 40-year period (U.S. Army Corps of Engineers 1993). Based on 10 years of studies in both the main and east channels at Prairie du Chien (Miller and Payne 1991, 1992, 1993, 1994, 1995a, 1995b, 1996a, 1997), there have been no significant changes in populations. Intergenerational changes, however, could occur and 10 years is a small portion of the life span of many mussels. Tow traffic impacts should continue to be studied, particularly in main channel borders areas such as those at Prairie du Chien, Wisconsin, where tows move in close proximity to beds containing *L. higginsii*.

The types of activities currently affecting *L. higginsii* habitat on the UMRS are primarily related to the development of land-based, water-oriented facilities such as barge loading and off-loading sites, small boat harbors, dredging of access channels, construction of highway bridges and the establishment of fleeting areas. These can have negative impacts to mussels. Dredging access channels directly eliminates habitat and, over time, may cause the slumping of adjacent areas into the channel, further reducing available habitat. The operation of small boats and larger vessels (*e.g.*, casino boats) in the vicinity of mussel beds can have impacts through the redistribution of sediment or accidental spills of fuel and other contaminants. Fleeting barges over mussel beds may directly crush or bury mussels. Pier construction for new highway bridges has taken place in or near mussel beds.

To adequately address these threats, the goal 1D (limit construction in areas of essential *L. higginsii* habitat) must be implemented. In the event that impacts to *L. higginsii* cannot be avoided, they may be mitigated by the relocation of mussels before construction.

Water Quality (see Tasks under 1.5 and 2.3 in the step-down outline)

Water quality issues, including point and non-point contaminant and pollutant sources, and chronic and episodic events, have not been documented as presently having significant adverse impacts to *L. higginsii*. The fact that impacts have not been documented is perhaps as much a consequence of the lack of investigation as of lack of actual impact. Contaminants and pollutants may have had a role in the presumed decline of the species; they may be presently affecting *L. higginsii* abundance, distribution, and health; and they may be rendering otherwise suitable potential reintroduction areas unfit for the species. Harm to *Lampsilis higginsii* has not been documented as a result of a single contaminant spill or other short-term contaminant episode, but such episodes have been strongly implicated in mussel die-offs elsewhere (Sheehan *et al*. 1989). The presumption must be that *L. higginsii* are as vulnerable to contaminant events as are other mussel species and accidental or unintended contaminant events that occurred elsewhere could also occur where *L. higginsii* is present.

This lack of information and documentation is itself the most significant water-quality related threat to *L. higginsii*. Undocumented harm may be occurring because of the limited availability of data assessing the significance of specific water and sediment quality parameters in relation to life cycle requirements of the species. Data gaps identified in the Water Quality section of this document include the unknown relative susceptibilities of the different life stages to contaminants, as well as the need for comparative data on the different modes of potential contaminant uptake (food sources, surface water, pore water, sediments). Related water quality information at areas designated as, or considered for, *L. higginsii* Essential Habitat Area can then be better evaluated to more effectively manage the recovery of the species. Additional information is also needed to improve laboratory culture and toxicity study requirements for freshwater mussels, thereby facilitating the documentation and use of toxicity data for *L. higginsii*.

Water quality parameters identified to potentially affect *L. higginsii* include un-ionized ammonia, select metals, and possibly some organic compounds. Although these contaminants may exist at varying concentrations throughout the UMRS, the species' preferred habitat (coarser substrates in main channel and channel borders) generally would not contain toxic concentrations of these contaminants in finer substrates of depositional areas, thereby offsetting much of the potential threat. Consequently, environmental perturbations resulting from episodic events are probably the most likely water quality factors to affect the recovery of *L. higginsii*. Such events may include spills of oil or hazardous materials, seasonal-runoff or "flushing" of contaminants into river systems, and water development projects unintentionally releasing contaminants from previously deposited sediments. The relative immobility of mussels, combined with the potentially high toxicity associated with such releases, increases the significance of these types of threats to *L. higginsii*.

Both point source discharges and non-point-runoff represent continuing threats to the species. Without the referenced toxicity data, however, it is unknown what water quality criteria or guidelines for specific contaminant or pollutant levels are necessary to protect *L. higginsii* in areas influenced by permitted point-source discharges. Low flow river conditions may result in increased concentrations of contaminants and thus increase impacts to the species from compounds such as un-ionized ammonia associated with fine sediments.

Commercial Harvest (see Tasks under 1.7 in the step-down outline)

The commercial harvest of mussels in the Upper Mississippi River peaked during the pearl button period of the 1920s and later during the cultured pearl era in the late-1980s and early 1990s (Thiel and Fritz 1993). The five Upper Mississippi River States (Iowa, Illinois, Minnesota, Missouri and Wisconsin) have regulated mussel harvest since the latter portion of the pearl button era in the late 1930s (Waters 1980) and are continuing to revise the regulations to strive for uniformity among the states and to reflect present-day biological data and concerns.

No commercial harvest is presently allowed in the Wisconsin and St. Croix Rivers or at the Sylvan Slough refuge on the Mississippi River. However, there is concern over potential illegal harvest in these areas. Officials indicate that mussel poaching in other areas of the U.S. is an increasing problem (Luoma 1997). Gary Jagodzinski (special agent, USFWS, pers. comm.) has indicated that at least 100 cases of illegal take, record keeping and sales violations were made in Wisconsin during 1996 in the Mississippi River or other inland waters. Most violations were for record keeping violations or illegal take such as undersized or prohibited species. Increased enforcement activities at sites in the Wisconsin and St. Croix Rivers and at the Sylvan Slough refuge on the Mississippi River is recommended. In other Essential Habitat Areas, the recovery team recommends that harvest be eliminated.

There are few documented reports of commercial clammers taking *L. higginsii*. Other than harvest activities such as brailing that may have influenced the entire mussel community, little is known regarding the direct impacts of commercial harvest on *L. higginsii.* Mathiak (1979), based on observations he made at a commercial clamming operation, concluded that hundreds of *L. higginsii* had probably been harvested in 1975 before the species was placed on the list of Threatened and Endangered Species.

Conservation Measures

There were four recommendations for immediate action in the initial Higgins' Eye Pearlymussel Recovery Plan. In this section we review the progress that has been made on these recommendations and other actions that have been taken to conserve the species.

The following were recommendations for immediate action:

1. Conduct ten-year field studies in Essential Habitat Areas (with initial emphasis on the Prairie du Chien site) to determine the status of each population and its habitat.

2. Develop relocation (translocation) techniques for Higgins' Eye Pearlymussels.

3. Develop artificial propagation techniques. This should include a thorough literature review, development of methodology, testing of methodology on closely related, non-endangered species, propagation of Higgins' Eye Pearlymussels, and determination of suitable stocking sites.

4. Develop uniform regulations concerning clam harvesting methods that would best manage and protect the resource. These regulations should be developed cooperatively by the states, the USFWS, and commercial clammers. Two specific items that should be included in the development of these regulations are:

    a. Policies restricting dredging as a method of commercial harvesting clams on the Mississippi River, and

    b. A study to determine the potential beneficial and/or detrimental effects of brailing on mussel beds, relative to other harvesting methods (such as diving), with subsequent appropriate regulation.

<u>Ten-Year Field Studies in Essential Habitat Areas</u>

There have been a number of studies of *L. higginsii* since the initial recovery plan was written (Table 6 - Cawley 1996 - see Section IV). Only studies by Miller and Payne (1991, 1992, 1993, 1994, 1995a, 1995b, 1996a, 1997) have chronicled the change in mussel communities over a ten-year period. Their work was conducted at Prairie du Chien and, although not directly related to the assessment of *L. higginsii* populations, gives insight into the long-term trends in mussel communities that contain the endangered *L. higginsii*.

<u>Development of Relocation (Translocation) Techniques</u>

As stated by Waller *et al*. (1995), "State and Federal agencies are actively conducting ... relocation operations in an effort to preserve the remaining unionid fauna. Information of threshold and tolerance limits of different mussel species to collection and handling conditions is especially critical at this time for planning management and conservation activities for unionid mussels." Although they did not specifically examine *L. higginsii,* they conclude that with proper precautions, handling and exposure to the atmosphere associated with relocation efforts should not cause significant levels of mortality in unionid mussels.

A number of relocations of *L. higginsii* have occurred since the initial recovery plan was developed. Before 2000 these relocations were usually associated with construction projects and were not designed to examine the effects of relocation methods on the mussels. However, one relocation project at the I-94 bridge over the St. Croix River included a monitoring program designed specifically to examine the effects of handling, placement methods, and buffer zones on the survivorship of relocated mussels (Dunn 1996a, 1996b).

Oblad (1980) discussed a relocation experiment with *L. higginsii* at Sylvan Slough, one of the Essential Habitat Area Sites designated in the initial Recovery Plan (Table 6 - see Section IV). Three *L. higginsii* were collected from mid-channel and were relocated nearby. A year following the relocation all three *L. higginsii* were recovered.

The US Highway 10 bridge over the St. Croix River near Prescott, Wisconsin, was replaced in 1988 and mussels were transplanted to a region upstream of the project (Heath 1989). Nearly 8000 mussels were transplanted including 42 *L. higginsii*. A large number of the mussels from this relocation died, including > 30 *L. higginsii*, possibly because the relocation took place when air and water temperatures were too low and because the mussels may have been harmed by a water surface oil sheen they were exposed to during the relocation effort (Paul Burke, USFWS, pers. comm.). However, when Hornbach *et al.* (1995), sampled the relocation bed in 1994, seven *L. higginsii* relocated in the 1988 project were found. Some of these specimens had experienced measurable growth, and all appeared to be in good condition.

The I-94 bridge over the St. Croix River at Hudson, Wisconsin, has been replaced. This project over the St. Croix River required the relocation of 9,042 mussels in 1994 (Dunn 1996a) and 14,043 mussels in 1995 (Dunn 1996b). A total of 43 *L. higginsii* were moved in 1994 and 36 were moved in 1995. A two-year monitoring program was developed for each year to (1) evaluate overall mussel survival, (2) growth and survival of endangered species, including *L. higginsii*, (3) handling methods, (4) placement methods, and (5) buffer zone size. At each relocation phase, mortality was assessed at one month, one year and two years after relocation. Results of two years of monitoring of the 1994 relocation yielded one dead *L. higginsii* and an average increase in shell length for 35 *L. higginsii* of 4.2 mm (Dunn 1996a). Results of one year of monitoring of the 1995 relocation also yielded only one dead *L. higginsii*; average shell length had increased 1.3 mm (Dunn 1996b). Results of monitoring the general population and experimental subsamples will be used to develop guidelines for future relocation projects.

In 1996, an *in-situ* relocation project was begun in the St. Croix River (Waller, pers. comm.). This project involves the refinement of protocols for relocating mussels to *in-situ* refugia from zebra mussels and to assess the suitability of potential refugia for mussels in the St. Croix River. One hundred *L. higginsii* mussels were relocated from the St. Croix River at Hudson, Wisconsin, upstream to a site near Franconia, Minnesota. Mussels will be monitored for a minimum of two years to evaluate growth and survival at the refugium site relative to those at the source site.

In 2000, state and federal agencies markedly increased their attempts to relocate *L. higginsii* to reduce their exposure to zebra mussels. As stated above, the USFWS issued a Biological Opinion to the Corps' on May 15, 2000 that required the Corps to (1) conduct a Higgins' eye relocation feasibility analysis and (2) prepare a Higgins' eye Pearlymussel Relocation Plan. As a result, the Corps drafted seven interim and long-term objectives to conserve Higgins' eye associated with the continued operation and maintenance of a nine-foot navigation channel in the Upper Mississippi River. One of these objectives, Objective 3, is to "Establish a minimum of five new and viable populations of Higgins' eye in the UMRS and/or tributaries un-infested or with low level infestations of zebra mussels." Work toward this objective has resulted in several relocation attempts (Table 1) and additional attempts are likely to continue for several more years. Of the 63 *L. higginsii* recovered in 2002 at the Hidden Falls (Pool 2) and Hastings (Pool 3) adult relocation sites (59 females, 4 males), only one was found dead, although several had abnormal growth patterns exhibited by "exaggerated growth arrest lines and in-turning along the ventral margin of the shell" (Davis 2003).

<u>Development of Artificial Propagation Techniques</u>

The recent and severe infestation of the Upper Mississippi River and several tributaries by zebra mussels has significantly raised the importance of the development of artificial propagation techniques for the conservation of *L. higginsii*. Before 2000, workers had explored a variety of techniques for propagating this and other mussel species, including the use of artificial media. Since 2000, however, propagation has mostly focused on the artificial infestation and release of fish into areas where zebra mussels are not an imminent threat.

Waller and Kammer (1985) indicated that a surrogate for *L. higginsii* (*L. cardium*) could artificially infect largemouth bass and walleye. They compared the propagation of *L. higginsii* glochidia in an artificial medium with the use of infected fish in the laboratory (Holland-Bartels and Waller 1988). They were able to successfully transform glochidia with the artificial medium and by infecting fish. Waller and Kammer (1985) indicated that both techniques have potential use for the production of juvenile mussels. Welke *et al*. (2000) used similar techniques to artificially infect largemouth bass and walleye with *L. higginsii* glochidia. Results from the walleye treatment were confounded after an ectoparasitic infection resulted in total fish mortality, but some juvenile mussels successfully excysted from walleye gill tissue incubated in a separate water system and from largemouth bass. Further work on congeners of *L. higginsii* by Holland-Bartels and Zigler (1990) showed that nutritional requirements appeared to be a factor limiting successful laboratory culture of glochidia. They used a combined laboratory/field culture approach to bypass this area of difficulty by infecting fish in the laboratory and then stocking them in the field in floating cages just before metamorphosis. Gordon (2001, 2002) has found greater transformation success with centrarchids (*e.g.*, smallmouth bass) than with percids (walleye) at Genoa National Fish Hatchery. A number of other studies have examined artificial propagation techniques in other species of freshwater mussels (Watters 1994b; Beaty and Neves 1996; Gatenby *et al.* 1997; O'Beirn *et al.* 1998; and references therein).

As with adult translocation, artificial propagation of Higgins' eye has increased greatly since the issuance of the Biological Opinion to the Corps in 2000 (see above). Biologists have collected gravid Higgins' eye from several locations each year between 2000-2002, taken them to Genoa National Fish Hatchery (Hatchery), and infested fish using the methods described by Welke *et al.* (2000). In May 2002, workers infested 7466 fish (largemouth bass, smallmouth bass, and walleye) with Higgins' eye glochidia at the Hatchery. A portion of the fish were retained at the Hatchery to refine techniques for producing juvenile Higgins' eye, but most were kept in the Hatchery for about three weeks before being sent to release sites. At these sites, workers simply released the fish to swim freely or confined them in cages secured to the river bottom (Table 1). Cages facilitate monitoring of transformation success and, in some cases, are used to grow juvenile Higgins' eye for release elsewhere (M. Davis, Minnesota Department of Natural Resources, Lake City, MN, pers. comm. 2002). Fish are released from cages after glochidia have excysted.

Biologists have found juvenile Higgins' eye (*i.e.*, less than < 30 mm) in or beneath cages containing infested largemouth bass, smallmouth bass, and walleye in at least five of the caged fish releases shown in Table 1. Confirmation of success (*i.e.*, transformation of glochidia to independent juveniles) or failure of the caged fish releases is not always possible; a few attempts likely failed due to excessive sedimentation. Therefore, biologists have rejected sites subject to significant sediment deposition. There are no data to evaluate the success of the free-swimming fish releases.

Biologists involved in propagation of Higgins' eye continue to refine propagation and release techniques (Gordon 2002). Pre-release mortality of infested fish has been significant (*e.g.*, >20%) in some cases and may be exacerbated by the stress of the mussel infestation process (Gordon 2002). Gordon (2002) counted the number of glochidia and number of juveniles that transformed from a subset of the fish that were inoculated in 2002. Number of glochidia per fish ranged from 146-283 and transformation to the independent juvenile stage in the Hatchery was 38-47%. Assuming that the percent transformation is similar in released fish, a cage of 100 infested fish may produce approximately 4000 juvenile Higgins' eye. Although transformed juveniles have been recovered from some of the cages, there are no data to estimate the proportion of glochidia that survive to the independent stage in this setting. Attempts to support the transformation and initial growth of juveniles in the Hatchery have been hampered by fish mortality, introduction of mussel predators into the culture facilities, and power failures (Gordon 2001, 2002). Nevertheless, approximately 8000 juvenile *L. higginsii* have been released in four separate events since 2000.

Development of Uniform Regulations Concerning Clam Harvesting Methods

Sparks and Blodgett (1983) conducted a study to examine the effects of three types of mussel harvest methods: crowfoot bar (brail), basket dredge and diver. They indicated that crowfoot bar and diving resulted in less dislodgement and damage than the basket dredge. Based on their work they supported Illinois' prohibition of basket dredges and recommended that hand dredges also be banned. They indicated that diving appeared to be the least harmful and most selective method for harvesting mussels. They also indicated that the crowfoot bar should be retained as a legal device because it appeared to be fairly non-destructive and was safer than diving.

Thiel and Fritz (1993) have reviewed the history of mussel harvest and regulation in the UMRS. They indicated that there has been significant improvement in the coordination among the states of the Upper Mississippi River regarding mussel harvest. The main results of the improved coordination are restricted seasons for harvest, size limits for harvest, and the requirement for permit or license in each state. Prime among these are restricted seasons for harvest in each state. As of 1996, only Minnesota had outlawed the use of brailing. Illinois was the only State that still allowed the use of a hand fork. Thiel and Fritz (1993) did not comment on the impact of improved harvest regulations on the viability of *L. higginsii* populations. They did indicate that harvest impact has been great on the washboard (*Megalonaias nervosa*), and that catch-per-unit-effort has declined since 1990, partially due to the increase in the minimum size limits for live washboards put in place in 1990. This decrease in catch-per-unit-effort has led to an increase in price. They also indicated that slow-growing washboard populations may no longer be able to keep up with the harvest pressure. They concluded by indicating that there must be sound scientific management of this resource.

In 1996, the Upper Mississippi River Conservation Committee (UMRCC) Executive Board approved a set of proposed mussel regulations developed by the Fisheries Technical Section's *ad hoc* mussel committee (P. Thiel, USFWS, pers. comm. 1996). The recommendations were crafted in cooperation with representatives of the Shell Exporters of America, Inc. The goals of the proposed regulation are to: 1) move toward standardizing mussel harvest regulations among the five UMRCC states, 2) close loopholes which make enforcement of existing regulations difficult, and 3) protect populations of species, such as washboard, *Megalonaias nervosa*, from overharvest, with a long-term purpose of sustained harvest of freshwater mussels in the Upper Mississippi River. The proposed regulations address eleven different topics, including season, gear, size limit, license fees, and reporting, and are being routed through each UMRCC member state's natural resource agency for consideration and potential rule-making. The new rules will not all be in place until at least 1998, and it is unlikely that all five states will adopt all of the regulations. However, this is an attempt to develop more uniform regulations for the benefit of the native mussel fauna.

II. RECOVERY

Recovery Strategy

This revised recovery plan adopts the approach of the previous recovery plan for *L. higginsii* by focusing recovery on the conservation of the species at identified Essential Habitat Areas. In the 1983 recovery plan, Essential Habitat Areas were specific areas throughout the historical range of *L. higginsii* that supported dense and diverse mussel beds where *L. higginsii* was successfully reproducing. This revised recovery plan identifies three additional "Essential Habitat Areas" (Orion, WI, Prescott, WI, and Interstate Park, MN/WI), but also outlines specific criteria for evaluating additional areas for this designation. The plan recommends the development of a uniform protocol for collecting information on populations of *L. higginsii*. Use of this protocol will allow for ongoing evaluation of the list of Essential Habitat Areas and progress towards recovery.

The highest priority recovery actions for *L. higginsii* are primarily intended to address the severe impacts and threats posed by zebra mussels. Of the ten Essential Habitat Areas designated in this revised plan, zebra mussels have had severe impacts on the mussel communities at Harpers Slough, Prairie du Chien, and Cordova and are imminent threats at the Prescott, and Hudson, WI areas. The Prairie du Chien Essential Habitat Area, for example, may have contained the largest population of *L. higginsii* before its severe infestation by zebra mussels, but Miller and Payne (2001) found nearly 10,000 zebra mussels/m^2 in this area in 2000.

The removal of zebra mussels in a manner and scale necessary to benefit *L. higginsii* is evidently not currently feasible. Therefore, the plan focuses on developing methods to prevent new infestations, monitoring zebra mussels at Essential Habitat Areas, and developing and implementing contingency plans to alleviate impacts to infested populations. Based on recent activities, the latter may consist largely of removing *L. higginsii* from areas where zebra mussels pose an imminent risk to the persistence of the population and releasing them into suitable habitats within their historical range where zebra mussels are not an imminent threat. Within the last two years, workers have removed 471 adult *L. higginsii* from areas near Cassville, WI and Cordova, IL on the Upper Mississippi River and relocated them into Pools 2 and 3 near Minneapolis, MN and Hastings, MN, respectively (Table 1). Cleaning fouled adults *in situ* and artificial propagation and release (Table 1) are also currently being implemented in an attempt to alleviate the effects of zebra mussels on the conservation of *L. higginsii*.

Although zebra mussels are currently the most important threat to *L. higginsii*, construction activities and environmental contaminants may also pose significant threats. Therefore, the Corps and other agencies must continue to assess and limit the potential impacts of their actions on *L. higginsii*. The plan also outlines tasks needed to improve our understanding of the potential importance that contaminants play in the conservation of *L. higginsii* and calls on the U.S. Coast Guard, Environmental Protection Agency, and other agencies to take actions to minimize the potential impacts of toxic spills.

Interagency partnerships will be key to the recovery of *L. higginsii*. In addition to the USFWS, the Implementation Table identifies five other federal agencies and four states as being responsible for various aspects of the recovery of the species. The U.S. Army Corps of Engineers, for example, is called on to implement several of the tasks. The Corps' implementation of the 2000 Biological Opinion on continued operation and maintenance and operation of the 9-foot navigation channel has resulted in the formation of the Mussel Coordination Team (MCT). This MCT has implemented extensive relocation and reintroduction of *L. higginsii* since 2000 (Table 1). These activities, although necessary to avoid jeopardizing the species, are leading to the development and refinement of techniques for propagating *L. higginsii* and other mussel species.

Recovery Goals and Interim Recovery Criteria

The criteria for meeting the recovery goals are interim because further work (see below) is necessary to make them fully measurable. The tasks that are necessary to make the criteria fully measurable are outlined below and are included in the Narrative Outline for Recovery Activities and in the Implementation Table.

Goal 1: Reclassify *Lampsilis higginsii* to Threatened Status

Interim Criteria for Goal 1 (Reclassification)

5. *Lampsilis higginsii* may be considered for reclassification from Endangered to Threatened when at least five identified Essential Habitat Areas contain reproducing, self-sustaining populations of *L. higginsii* that are not threatened by zebra mussels. The five Essential Habitat Areas include the Prairie du Chien Essential Habitat Area and at least one Essential Habitat Area each in the St. Croix River and in Mississippi River Pool 14.

    a. *L. higginsii* populations will be considered to be "reproducing" if there is evidence that they include a sufficient number of strong juvenile year classes.[5]

    b. Populations will be considered to be "self-sustaining" if they have maintained stable or increasing population densities for at least twenty years.

    c. Each identified Essential Habitat Area will be considered to be "not threatened by zebra mussels" if zebra mussel densities have not increased for five consecutive years.[6] This criterion will not be met if there is one or more newly discovered or expanded population of zebra mussels in a location where they or their offspring

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[5] *L. higginsii* less than 20 mm in length will be assumed to be juveniles.

[6] For analyses of zebra mussel and Higgins' eye population trends, use a significance level (ζ)#Ω0.2 and power#∅0.9 for all tests.

may affect *L. higginsii* populations in one or more of the identified Essential Habitat Areas. The USFWS will make this determination by evaluating water velocities, larval development times, and distances between any newly discovered or expanded zebra mussel population and any of the five identified Essential Habitat Areas. If there is a possibility that veligers from any newly discovered or expanded zebra mussel population will settle in any of the identified Essential Habitat Areas, this recovery criterion will not be met until an additional three years of zebra mussel sampling indicates that zebra mussel densities are not increasing in any of the potentially affected Essential Habitat Areas.

The following questions must be answered to make this criterion fully measurable. These are included in the Narrative Outline for Recovery Activities and in the Implementation Table as part of Task 1.2.2, a Priority 1 task.

i. What would constitute sufficient evidence of a strong juvenile year class?

ii. What methods should be used to evaluate the strength of juvenile year classes?

iii. How many strong juvenile year classes should be detected to determine that reproduction is sufficient to allow for stable or growing populations?

6. Complete the following tasks to determine if water quality criteria for Goal 2 (Delisting) are necessary to ensure the conservation of *L. higginsii* and, if so, to develop measurable water quality criteria for Goal 2.

   a. 1.5.1. Develop a freshwater mussel toxicity database for sediment and water quality parameters to define *L. higginsii* habitat quality goals. (7 sub-tasks)

   b. 1.5.2. Characterize specific sediment and water quality parameters in the ten *L. higginsii* Essential Habitat Areas. (1 sub-task)

7. Harvest of freshwater mussels is prohibited by law or regulation in Essential Habitat Areas. This applies to all Essential Habitat Areas, not just the five identified under criterion 1.

Goal 2: Delist *L. higginsii.*

Interim Criteria for Goal 2 (Delisting)

1. Delisting *L. higginsii* requires that populations of *L. higginsii* in at least five Essential Habitat Areas are reproducing, self-sustaining, not threatened by zebra mussels, and are sufficiently secure to assure long-term viability of the species. The five Essential Habitat Areas include the Prairie du Chien Essential Habitat Area and at least one Essential

Habitat Area each in the St. Croix River and in Mississippi River Pool 14. "Reproducing" and “self-sustaining” are to be fully defined above under Goal 1.

Populations at the identified Essential Habitat Areas will be “sufficiently secure to assure long-term viability of the species” if each of the following four conditions is met:

a. There is no indication that activities that are reasonably likely to occur in the foreseeable future will result in a change in the predominant substrate conditions within each identified Essential Habitat Area to shifting, unstable sands, silt, cobble, boulder, artificial substrates (*e.g.*, concrete), or substrates with rooted plants to the extent that such changes would appreciably reduce the likelihood of conserving the Higgins’ eye population in the Essential Habitat Area.

b. There is no indication that activities that are reasonably likely to occur in the foreseeable future will result in water quality characteristics (*e.g.*, high concentrations of un-ionized ammonia) in Essential Habitat Areas that have been shown to cause detrimental effects to *L. higginsii* or sympatric species to the extent that such effects would appreciably reduce the likelihood of conserving the Higgins’ eye population in the Essential Habitat Area.

c. There is no indication that construction of barge loading or off-loading sites, boat harbors, highway bridges, or fleeting areas or dredging of access channels are reasonably likely to occur in the foreseeable future within the identified Essential Habitat Areas to the extent that such construction or dredging activities would appreciably reduce the likelihood of conserving the Higgins’ eye population in the Essential Habitat Area.

d. Measures that provide for review of federally funded, permitted, or planned activities in or near *L. higginsii* habitat pursuant to the Fish and Wildlife Coordination Act and Clean Water Act are in place.

2. Each identified Essential Habitat Area will be considered to be “not threatened by zebra mussels” if zebra mussel densities have not increased for five consecutive years.[7] This criterion will not be met if there is one or more newly discovered or expanded population of zebra mussels in a location where they or their offspring may affect *L. higginsii* populations in one or more of the identified Essential Habitat Areas. The USFWS will make this determination by evaluating water velocities, larval development times, and distances between any newly discovered or expanded zebra mussel population and any of the five identified Essential Habitat Areas. If there is a possibility that veligers from any newly discovered or expanded zebra mussel population will settle in any of the identified Essential Habitat Areas, this recovery criterion will not be met until an additional three

[7] For analyses of zebra mussel and Higgins’ eye population trends, use a significance level /ζ0ɫΩ0.2 and power ∅0.9 for all tests.

years of zebra mussel sampling indicates that zebra mussel densities are not increasing in any of the potentially affected Essential Habitat Areas.

3. The use of double hull barges is required at and upstream of each of the identified Essential Habitat Areas that may otherwise be threatened by spills from commercial barges.

4. *L. higginsii* habitat information and protective responses to conserve each of the identified Essential Habitat Areas have been incorporated into all applicable spill contingency planning efforts.

5. Harvest of freshwater mussels is prohibited by law or regulation in Essential Habitat Areas. This applies to all Essential Habitat Areas, not just the five identified under criteria numbers 1-4.

6. Water quality criteria may be added to the criteria for Goal 2 (Delisting) upon completion of the tasks referred to under the Criteria for Goal 1 (Reclassification, see 2a-b above and Tasks 1.5.1 and 1.5.2).

Narrative Outline for Recovery Activities

1 Preserve *L. higginsii* and its Essential Habitat Areas.

1.1 Assess and limit impact of the zebra mussel, *Dreissena polymorpha*, on *L. higginsii*.

1.1.1 Develop strategies to prevent zebra mussel infestation.

1.1.2 Monitor zebra mussel populations at Essential Habitat Areas that are currently infested.

1.1.3 Develop and implement an emergency response plan in the event of a demonstrable impact of zebra mussels on *L. higginsii* in Essential Habitat Areas.

On January 26, 2001, the Higgins' Eye Pearlymussel Recovery Team met and set the following objective and goals for a zebra mussel emergency response plan:

Objective: To mitigate effects of zebra mussels to facilitate recovery of *Lampsilis higginsii* and to allow eventual delisting.

Goals:

1. Prevent infestation of occupied habitats that are not yet infested.

2. Determine whether, and how, *L. higginsii* essential habitat areas should be redefined.

3. Minimize loss of *L. higginsii* in areas already infested by zebra mussels, including restoration of habitat suitability (*i.e.*, reducing or removing zebra mussels), where feasible.

1.2 Develop uniform protocols for collecting and maintaining information on *L. higginsii* populations.

1.2.1 Develop a uniform protocol for collecting information for populations of *L. higginsii.*

1.2.2 Answer the following three questions to make the recovery criteria fully measurable:

1. What would constitute sufficient evidence of a strong juvenile year class?

2. What methods should be used to evaluate the strength of juvenile year classes?

3. How many strong juvenile year classes should be detected to determine that reproduction is sufficient to allow for stable or growing populations?

Answers to these questions are necessary to help make the recovery criteria measurable.

1.2.3 Develop a central database of information based on the protocol developed in task 1.2.1.

1.2.4 Develop and implement a long-term monitoring plan at Essential Habitat Areas.

1.3 Confirm and modify the list of seven Essential Habitat Areas in the initial recovery plan.

1.3.1 Reconfirm the Essential Habitat Areas from the initial recovery plan.

1.3.2 Identify new Essential Habitat Areas.

This plan already identifies three new Essential Habitat Areas and contains criteria for any additional Essential Habitat Areas.

1.3.2.1 Survey Pool 10; identify additional Essential Habitat Areas.

1.3.2.2 Examine a site near river mile 454, Muscatine, Iowa, for inclusion as an Essential Habitat Area.

1.3.2.3 Examine a site near river mile 556.4, Bellevue, Iowa, for inclusion as an Essential Habitat Area.

1.3.3 Estimate population size in Essential Habitat Areas.

1.3.4 Estimate recruitment in Essential Habitat Areas.

1.3.5 Estimate the existing genetic variability of the populations in Essential Habitat Areas.

Conduct genetic studies on the populations of *L. higginsii* in Essential Habitat Areas to assess the number of populations needed to ensure the maintenance of the species' genetic diversity.

1.4 Limit construction in areas of essential *L. higginsii* habitat. Mitigation, including translocation, may be an acceptable alternative in limited instances.

1.4.1 Determine the potential impact of construction projects on Essential Habitat Areas.

1.4.2 Determine alternatives to harmful construction practices.

Ensure that water development projects are designed and reviewed to minimize the potential for resuspension of contaminated sediments in the vicinities of *L. higginsii* Essential Habitat Areas.

1.4.3 Continue monitoring the impacts of commercial navigation activities on Essential Habitat Areas.

1.5 Continue to examine the relationship between water quality, especially contaminants, and *L. higginsii* populations in Essential Habitat Areas.

To most effectively address water quality threats discussed in this document, it is recommended that priority be given to filling data gaps identified under *Water Quality*. As *L. higginsii* toxicity data becomes more available, the relative degree of other water quality-related threats may be better evaluated. In summary, there is need to (1) obtain information on the water and sediment quality requirements of the various life history stages of *L. higginsii*, and (2) take concurrent actions to prevent acute and chronic, point and non-point source contamination that is reasonably presumed harmful to the species.

1.5.1 Develop a freshwater mussel toxicity database for sediment and water quality parameters to define *L. higginsii* habitat quality goals.

1.5.1.1 Identify suitable surrogate species for *L. higginsii* for use in laboratory toxicity tests.

1.5.1.2 Determine necessary handling protocols and culturing requirements of each life history stage to be tested.

1.5.1.3 Document existing toxicity data (including test type) available for the species and/or its surrogates.

1.5.1.4 Identify inorganic and organic contaminant compounds and mixtures present in *L. higginsii* Essential Habitat Areas. Use these data to determine realistic ranges of environmental concentrations for use in laboratory exposures.

1.5.1.5 Design and complete acute and chronic laboratory toxicity tests based on Tasks 1.5.1.1 through 1.5.1.4. Include glochidium, juvenile, and adult life stages.

Determine effects of organic and inorganic environmental contaminants identified under 1.5.1.4.

1.5.1.6 Document the exposure pathways and various modes of contaminant uptake for *L. higginsii* (or suitable surrogate species), emphasizing the relative significance of uptake from food sources, surface water, pore water, and sediments.

1.5.1.7 Determine the biological effects and significance of contaminant residues documented in mussel tissues.

1.5.2 Characterize specific sediment and water quality parameters in *L. higginsii* Essential Habitat Areas and reestablishment areas.

1.5.2.1 Collect sediment and pore water from areas identified as currently supporting viable *L. higginsii* populations and proposed reestablishment areas; analyze for a range of organic and inorganic contaminants.

This is especially important in the Sylvan Slough area of Upper Mississippi River Pool 15, where the potential for PCBs in sediments to adversely affect benthic biota has been identified.

1.5.3 Promote best management practices in the watersheds of *L. higginsii* Essential Habitat Areas and relocation areas to minimize potential non-point source impacts.

Water quality threats to *L. higginsii* and to future reintroduction efforts may be reduced by ensuring that water development projects minimize re-suspension of contaminated sediments in vicinities of *L. higginsii* Essential Habitat Areas and potential reestablishment areas. Best management practices (erosion control, cropping systems, livestock waste management, etc.) recommended and approved by the U.S. Department of Agriculture and the U.S. Environmental Protection Agency should continue to be encouraged in the watersheds of Essential Habitat Areas to minimize potential run-off impacts to the species.

1.5.3.1 Coordinate with local land use planning and technical assistance offices to increase awareness and need to protect water quality in *L. higginsii* Essential Habitat Areas and relocation areas.

1.6 Develop plans to enhance the safety of shipping toxic or hazardous materials, reduce the introduction of these materials near *L. higginsii* habitat and develop response plans for any spills that may occur.

1.6.1 Promote the use of double hull barges.

1.6.2 Incorporate *L. higginsii* habitat information into applicable spill contingency planning efforts; identify protective response actions available.

1.6.2.1 Coordinate with state and Federal natural resource trustees responsible for spill planning and response. Identify *L. higginsii* water quality requirements and Essential Habitat Area information, as well as applicable facility, local, state, Federal, and area spill contingency planning efforts.

1.6.2.2 Identify potential response actions that may prevent/minimize impacts to *L. higginsii* (including habitat) in the event of a spill of oil or hazardous materials. Incorporate into applicable response plans as necessary.

1.6.2.3 Identify potential *L. higginsii* habitat restoration and compensation measures that state and Federal natural resource trustees may consider under Natural Resource Damage Assessment responsibilities in the event of a spill of oil or hazardous materials. Incorporate into applicable response plans as necessary.

1.7 Review current regulations of mussel harvest in the upper Mississippi River drainage and develop additional regulations to reduce impacts on *L. higginsii*.

1.7.1 Develop regulations to prevent mussel harvest in Essential Habitat Areas.

1.7.2 Review existing harvest regulations and make recommendations to the Service and the states on any needed regulations.

1.7.3 Enhance enforcement of existing harvest regulations.

1.8 Continue to develop materials to inform the public on the nature of endangered mussels and *L. higginsii*, in particular.

1.8.1 Continue to develop materials to inform commercial navigation industry, commercial harvesters and state transportation agencies on the nature of endangered mussels.

2 Enhance the abundance and viability of *L. higginsii* in areas where it currently exists and restore populations within historic range.

2.1 Identify and rank potential sites of existing *L. higginsii* populations for enhancement including Essential Habitat Areas.

2.1.1 Estimate the population size in non-Essential Habitat Areas.

2.1.2 Estimate recruitment in non-Essential Habitat Areas.

2.1.3 Estimate the genetic variability of the populations in non-Essential Habitat Areas.

2.2 Increase the number of *L. higginsii* at enhancement sites to current levels found in Essential Habitat Areas or to numbers appropriate for the local habitat.

2.2.1 Determine the best method to increase population size.

2.2.2 Utilize the best method to increase population size.

2.2.3 Assess the efficacy of the method used.

2.3 Determine the feasibility of reestablishing *L. higginsii* into historic habitats, particularly streams that are at lower risk for zebra mussel colonization.

2.3.1 Rank historic habitats for the likelihood of zebra mussel colonization.

2.3.2 Examine habitat suitability and fish assemblage for reintroduction.

Sediment and water quality should be characterized in areas designated for reestablishment; comparisons to sediment and water quality parameters in existing *L. higginsii* habitat should provide at least a partial indication of habitat integrity.

2.3.3 Utilize best method of reintroduction.

2.4 Examine the taxonomic validity of *L. higginsii* especially since *L. abrupta* is found in noncontiguous geographic areas.

2.4.1 Examine the morphological, conchological and genetic differences between *L. higginsii* and *L. abrupta*.

III. IMPLEMENTATION SCHEDULE

The following Implementation Schedule outlines actions and estimated costs for the recovery program. It is a guide for meeting the objective discussed in Part II of this Plan. This schedule indicates task priorities, task numbers, task descriptions, duration of tasks, recovery partners, and estimated costs. These actions, when accomplished, should lead to the recovery of the species and protect its essential habitat. The estimated funding needs for all parties anticipated to be involved in recovery are identified. Part III reflects the estimated costs for the first three years of the recovery program for this species. Costs for year 4 and beyond will be determined approximately every three years by the USFWS and cooperating agencies. When delisting occurs, a minimum of five years of monitoring is required by the Act to assess the adequacy of recovery actions and determine if there will be cause to consider relisting. Because of special concerns with the biology of *Lampsilis higginsii*, a minimum of ten years of monitoring is necessary for this species.

Tasks in the first column of the following Implementation Schedule are assigned priorities as follows:

Priority 1: An action that ***must*** be taken to prevent extinction or to prevent the species from declining irreversibly in the ***foreseeable*** future.

Priority 2: An action that must be taken to prevent a significant decline in species population/habitat quality or some other significant negative impact short of extinction.

Priority 3: All other actions necessary to meet the recovery objectives.

Acronyms used in the Implementation Schedule:

ES-TE	U.S. Fish and Wildlife Service, Division of Ecological Services, Threatened and Endangered Species Program
ES-EQ	U.S. Fish and Wildlife Service, Division of Ecological Services, Environmental Quality Program
ES-HC	U.S. Fish and Wildlife Service, Division of Ecological Services, Habitat Conservation Program
F	U.S. Fish and Wildlife Service, Division of Fisheries
RW	U.S. Fish and Wildlife Service, Division of Refuges and Wildlife
EA	U.S. Fish and Wildlife Service, Division of External Affairs
LE	U.S. Fish and Wildlife Service, Division of Law Enforcement
Partners	U.S. Fish and Wildlife Service, Partners for Fish and Wildlife Program
ACOE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
USDA	U.S. Department of Agriculture
EPA	U.S. Environmental Protection Agency
BRD	U.S. Geological Survey, Biological Resources Division
WRD	U.S. Geological Survey, Water Resources Division
NPS	National Park Service
States	Minnesota Department of Natural Resources, Division of Ecological Services Wisconsin Department of Natural Resources, Bureau of Endangered Resources Iowa Department of Natural Resources, Division of State Parks, Recreation and Preserves Illinois Department of Natural Resources, Division of Natural Heritage Missouri Department of Conservation
TBD	To be determined. The Recovery Team was not able to estimate the costs of these tasks.

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
1.1. Assess and limit the impact of the zebra mussel, *Dreissena polymorpha*, on *L. higginsii*.									
1.1.1	1	Develop strategies to prevent zebra mussel infestation.	2	ES-TE	ACOE States BRD	50	50	---	
1.1.2	1	Monitor zebra mussel populations at Essential Habitat Areas that are currently infested.	Ongoing	ES-TE	ACOE States BRD	20	20	20	
1.1.3	1	Develop and implement a response plan in the event of a demonstrable impact of zebra mussels on *L. higginsii* in Essential Habitat Areas.	Ongoing	ES-TE	ACOE States BRD	30	50	50	year 2 and 3 cost only if plan is implemented
1.2. Develop uniform protocols for collecting and maintaining information on *L. higginsii* populations.									
1.2.1	2	Develop a uniform protocol for collecting information for populations of *L. higginsii*.	1	ES-TE	ACOE States BRD	50	---	---	

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
1.2.2	1	Answer the following three questions to make the recovery criteria fully measurable: 1. What would constitute sufficient evidence of a strong juvenile year class? 2. What methods should be used to evaluate the strength of juvenile year classes? 3. How many strong juvenile year classes should be detected to determine that reproduction is sufficient to allow for stable or growing populations?	3	ES-TE	States BRD	10	10	10	
1.2.3	2	Develop a central database of information based on the protocol developed in task 1.2.1.	1	ES-TE	ACOE States BRD	---	50	---	
1.2.4	2	Develop and implement a long-term monitoring plan at Essential Habitat Areas.	Cont.	ES-TE	States ACOE	100	100	100	
1.3. Confirm and modify the list of seven Essential Habitat Areas in the initial recovery plan.									
1.3.1	2	Reconfirm the Essential Habitat Areas from the initial recovery plan.	3	ES-TE	States BRD ACOE	100	100	100	
1.3.2	2	Identify new Essential Habitat Areas.	3	ES-TE	States BRD ACOE	100	100	100	

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
1.3.2.1	2	Survey Pool 10; identify additional Essential Habitat Areas.	3	ES-TE	States BRD ACOE	20	20	20	
1.3.2.2	3	Examine a site near river mile 454, Muscatine, IA, for inclusion as an Essential Habitat Area.	1	ES-TE	States BRD	10	---	---	
1.3.2.3	3	Examine a site near river mile 556.4, Bellevue, IA, for inclusion as an Essential Habitat Area.	1	ES-TE	States BRD ACOE	10	---	---	
1.3.2.4	3	Examine shallow shoreline habitats in Pool 14 to determine if these habitats may currently support significant unknown populations of *L. higginsii.*	1	ES-TE	States BRD ACOE	---	10	---	
1.3.3	2	Estimate population size in Essential Habitat Areas.	Cont.	ES-TE	States BRD	TBD	TBD	TBD	
1.3.4	2	Estimate recruitment in Essential Habitat Areas.	Cont.	ES-TE	States BRD	TBD	TBD	TBD	
1.3.5	3	Estimate the existing genetic variability of the populations in Essential Habitat Areas.	3	ES-TE	States BRD	50	50	50	
1.4. Limit construction in areas of essential *L. higginsii* habitat. Mitigation, including translocation may be an acceptable alternative in limited instances.									
1.4.1	3	Determine the potential impact of construction projects on Essential Habitat Areas.	Ongoing & cont.	ES-HC	ACOE	TBD	TBD	TBD	

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
1.4.2	3	Determine alternatives to harmful construction practices.	Ongoing & cont.	ES-HC	ACOE	TBD	TBD	TBD	
1.4.3	3	Continue monitoring the impacts of commercial navigation activities on Essential Habitat Areas.	Ongoing & cont.	ES-HC	ACOE	50	50	50	
1.5. Continue to examine the relationship between water quality, especially contaminants, and *L. higginsii* populations in Essential Habitat Areas.									
1.5.1	3	Develop a freshwater mussel toxicity database for sediment and water quality parameters to help determine *L. higginsii* habitat quality goals.	---	ES-EQ F	BRD WRD EPA ACOE	---	---	---	Reference specific tasks for total 1.5.1 cost estimates and duration
1.5.1.1	3	Identify suitable surrogate species for *L. higginsii* for use in laboratory toxicity tests.	3	ES-EQ	EPA BRD	75	75	50	
1.5.1.2	3	Determine necessary handling protocols and culturing requirements of each life history stage to be tested.	3	F ES-TE	BRD EPA	50	50	50	
1.5.1.3	3	Document existing toxicity data (including test type) available for the species and/or its surrogates.	3	ES-EQ	BRD EPA	40	40	0	

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
1.5.1.4	3	Identify inorganic and organic contaminant compounds and mixtures present in *L. higginsii* Essential Habitat Areas. Use these data to determine realistic ranges of environmental concentrations for use in laboratory exposures.	3	ES-EQ	BRD EPA	75	75	40	
1.5.1.5	3	Design and complete acute and chronic laboratory toxicity tests based on Tasks Task 1.5.1.1 through Task 1.5.1.4. Include glochidium, juvenile, and adult life stages.	3	ES-EQ	BRD EPA ACOE	75	75	50	
1.5.1.6	3	Document the various modes of contaminant uptake for *L. higginsii* (or suitable surrogate species), emphasizing the relative significance of uptake from food sources, surface water, pore water, and sediments.	3	ES-EQ	BRD WRD EPA	100	100	50	
1.5.1.7	3	Determine the biological effect and significance of contaminant residues documented in mussel tissues.	3	ES-EQ	BRD WRD EPA	150	150	100	
1.5.2	3	Characterize specific sediment and water quality parameters in *L. higginsii* Essential Habitat Areas and reestablishment areas.	---	ES-EQ	BRD WRD EPA ACOE	---	---	---	Reference task 1.5.2.1 for 1.5.2 cost estimates and duration

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
1.5.2.1	3	Collect sediment and pore water from areas identified as currently supporting viable *L. higginsii* populations and proposed reestablishment areas; analyze for a range of organic and inorganic contaminants.	3	ES-EQ	BRD WRD EPA ACOE	150	150	100	
1.5.3	3	Promote best management practices in the watersheds of *L. higginsii* Essential Habitat Areas and relocation areas to minimize potential non-point source impacts.	Cont.	ES-EQ ES-TE RW Partners	States EPA USDA NPS	---	---	---	Reference 1.5.3.1 for 1.5.3 cost estimate
1.5.3.1	3	Coordinate with local land use planning and technical assistance offices to increase awareness and need to protect water quality in *L. higginsii* Essential Habitat Areas and relocation areas	Cont.	ES-EQ ES-TE RW Partners	States EPA USDA NPS	30	30	30	
1.6. Develop plans to enhance the safety of shipping toxic or hazardous materials, reduce the introduction of these materials near *L. higginsii* habitat, and develop response plans for any spills that may occur.									
1.6.1	2	Promote the use of double hull barges.	Ongoing	ES-TE	USCG	---	---	---	
1.6.2	3	Incorporate *L. higginsii* habitat information into applicable spill contingency planning efforts; identify protective response actions available.	On-going	ES-EQ ES-TE F RW LE	USCG EPA States NPS	---	---	---	Reference tasks 1.6.2.1, 1.6.2.2, and 1.6.2.3 for 1.6.2 cost estimate.

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
1.6.2.1	3	Coordinate with state and Federal natural resource trustees responsible for spill planning and response. Identify *L. higginsii* water quality requirements and Essential Habitat Area information, as well as applicable facility, local, state, Federal, and area spill contingency planning efforts.	On-going	ES-EQ ES-TE F RW LE	USCG EPA States NPS	10	10	10	
1.6.2.2	3	Identify potential response actions take may prevent or minimize impacts to *L. higginsii* (including habitat) in the event of a spill of oil or hazardous materials. Incorporate into applicable response plans as necessary.	On-going	ES-EQ ES-TE F RW LE	USCG EPA States NPS	10	10	10	
1.6.2.3	3	Identify potential *L. higginsii* habitat restoration and compensation measures take state and Federal natural resource trustees may consider under Natural Resource Damage Assessment responsibilities in the event of a spill of oil or hazardous materials. Incorporate into applicable response plans as necessary.	On-going	ES-TE ES-EQ F RW LE	States NPS	20	20	20	

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
1.7. Review current regulations and develop additional regulation of mussel harvest in the upper Mississippi River drainage to reduce impacts on *L. higginsii*.									
1.7.1	2	Develop regulations to prevent mussel harvest in Essential Habitat Areas.	1	ES-TE	States	---	---	---	
1.7.2	3	Review existing harvest regulations and make recommendations to the USFWS and the States on any needed regulations.	1	ES-TE	States	---	---	---	
1.7.3	2	Enhance enforcement of existing regulations.	Cont.	LE	States	---	---	---	
1.8. Continue to develop materials to educate the public on the nature of endangered mussels and *L. higginsii*, in particular.									
1.8.1	3	Educate commercial navigation industry, commercial mussel harvesters and state transportation agencies on the nature of endangered mussels.	On-going	ES-TE PA	ACOE States	10	---	---	

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
2.1. Identify and rank potential sites of existing *L. higginsii* populations for enhancement including Essential Habitat Areas.									
2.1.1	3	Estimate the population size in non-Essential Habitat Areas	3	ES-TE	BRD States	100	100	100	Combined with 2.1.2
2.1.2	3	Estimate recruitment in non-Essential Habitat Areas	3	ES-TE	BRD States	See 2.1.1	---	---	Combined with 2.1.1
2.1.3	3	Estimate the genetic variability of the populations in non-Essential Habitat Areas	3	ES-TE	BRD States	70	70	50	In con-junction with 2.1.1
2.2. Increase the number of *L. higginsii* at enhancement sites to current levels found in Essential Habitat Areas or to numbers appropriate for the local habitat.									
2.2.1	3	Determine the best method to increase population size.	2	ES-TE	BRD States	50	50	---	
2.2.2	3	Utilize the best method to increase population size.	2	ES-TE	BRD States	---	100	100	
2.2.3	3	Assess the efficacy of the method used.	2	ES-TE	BRD States	---	---	---	

Task Nos.	Task Priority	Task Description	Duration (Years)	Recovery Partner		Cost Estimate $ X 1000			Comments
				USFWS Program	Other	Year 1	Year 2	Year 3	
2.3. Determine the feasibility of reestablishing *L. higginsii* into historic habitats, particularly streams that are at lower risk for zebra mussel colonization.									
2.3.1	2	Rank historic habitats for the likelihood of zebra mussel colonization.	Ongoing	ES-TE	BRD States	---	---	---	Combine with 2.3.2
2.3.2	2	Examine habitat suitability and fish assemblage for reintroduction.	Ongoing	ES-TE	BRD States	100	100	100	Combine with 2.3.1
2.3.3	2	Utilize best method of reintroduction	Ongoing	ES-TE	BRD State	300	300	300	
2.4. Examine the taxonomic validity of *L. higginsii* especially since *L. abrupta* is found in noncontiguous geographic areas.									
2.4.1	3	Examine the morphological, conchological and genetic differences between *L. higginsii* and *L. abrupta*.	1	ES-TE	BRD States	---	---	25	

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IV. TABLES

Table 1. Summary of recent (2000-2003) reintroductions, adult translocations, and other releases of *Lampsilis higginsii.* Releases between sites in the same river include experimental releases and movements of adults and releases of artificially propagated *L. higginsii* into areas with low densities of zebra mussels. Largemouth bass, smallmouth bass, walleye, freshwater drum, spotted bass (*Micropterus punctucatus*), and white bass (*Morone chrysops*) were used as host fish species for artificial propagation. UMR = Upper Mississippi River.

Action	Source River	Relocation River	No Mussels	No. Fish
Adult Relocation	UMR	UMR	101	n/a
Adult Relocation	UMR	UMR	99	n/a
Adult Relocation	UMR	UMR	271	n/a
Infested Fish in Cage(s)	St. Croix River	St. Croix River	n/a	100
Infested Fish in Cage(s)	St. Croix River	St. Croix River	n/a	100
Infested Fish in Cage(s)	St. Croix River	St. Croix River	n/a	150
Infested Fish in Cage(s)	St. Croix River	St. Croix River	n/a	150
Infested Fish in Cage(s)	St. Croix River	St. Croix River	n/a	50
Infested Fish in Cage(s)	St. Croix River	St. Croix River	n/a	150
Infested Fish in Cage(s)	St. Croix River	UMR	n/a	150
Infested Fish in Cage(s)	St. Croix River	UMR	n/a	150
Infested Fish in Cage(s)	St. Croix River	UMR	n/a	100
Infested Fish in Cage(s)	St. Croix River	UMR	n/a	50
Infested Fish in Cage(s)	St. Croix River	Wisconsin River	n/a	445
Infested Fish in Cage(s)	St. Croix River	Wisconsin River	n/a	150
Infested Fish in Cage(s)	UMR	UMR	n/a	245
Infested Fish in Cage(s)	UMR	UMR	n/a	520
Infested Fish in Cage(s)	UMR	UMR	n/a	804
Release Free-Ranging Fish	UMR	Wapsipinicon River	n/a	1890
Release Free-Ranging Fish	St. Croix River	Cedar River	n/a	793
Release Free-Ranging Fish	St. Croix River	Cedar River	n/a	405
Release Free-Ranging Fish	St. Croix River	Wisconsin River	n/a	450

Table 1. Summary of recent (2000-2003) reintroductions, cont.

Action	Source River	Relocation River	No Mussels	No. Fish
Release Free-Ranging Fish	UMR	Cedar River	n/a	615
Release Free-Ranging Fish	UMR	Iowa River	n/a	1000
Release Free-Ranging Fish	UMR	Iowa River	n/a	11
Release Free-Ranging Fish	UMR	Iowa River	n/a	87
Release Free-Ranging Fish	UMR	Iowa River	n/a	577
Release Free-Ranging Fish	UMR	Iowa River	n/a	60
Release Free-Ranging Fish	UMR	Iowa River	n/a	615
Release Free-Ranging Fish	UMR	Iowa River	n/a	65
Release Free-Ranging Fish	UMR	Wapsipinicon River	n/a	620
Release Free-Ranging Fish	Wisconsin River	Wisconsin River	n/a	300
Release Juveniles	St. Croix River	Black River	1914	n/a
Release Juveniles	St. Croix River	Black River	1200	n/a
Release Juveniles	St. Croix River	St. Croix River	3	n/a
Release Juveniles	St. Croix River	Wisconsin River	3750	n/a
Release Juveniles	St. Croix River	Wisconsin River	1100	n/a

Table 2. List of primary and secondary habitats described in the 1983 *L. higginsii* recovery plan.

Habitat Type	Site	UMRS Pool	River Mile
Primary	Sylvan Slough, IL	15	485.5-486
	Cordova, IL	14	503-505.5
	McMillan Island, IA	10	616.4-619.1
	Prairie du Chien, WI/MN	10	634-636
	Harper's Slough, IA/WI	10	639-641.1
	Whiskey Rock, IA	9	655.8-658.4
	Hudson, WI (Lakeland, MN)	St. Croix River	16.2-17.6
Secondary	Jonas Johnson Island, IL	17	439
	Barkis Island, IL	17	444
	Andalusia Slough, IL	16	473
	Lower Sylvan Slough, IL	16	482
	Rapids City, IL	14	496
	Adams Island (vicinity), IA	14	507
	Dubuque, IA	12	580
	Cassville, WI	11	607
	Guttenberg, IA	11	613

Table 3. Fishes that have been examined as potential hosts for *L. higginsii.*

Fish species	Common name	Family	Suitability as a host	Reference
Stizostedion canadense	sauger	Percidae	Suitable	Surber (1912); Wilson (1916); Coker *et al.* (1921); Hove and Kapuscinski (2002)
Aplodinotus grunniens	freshwater drum	Sciaenidae	Suitable	Wilson (1916); Coker *et al.* (1921)
Micropterus salmoides	largemouth bass	Centrarchidae	Suitable	Sylvester *et al.* (1984); Waller & Holland-Bartels (1988); Hove and Kapuscinski (2002)
Micropterus dolomieu	smallmouth bass	Centrarchidae	Suitable	Waller & Holland-Bartels (1988)
Stizostedion vitreum vitreum	walleye	Percidae	Suitable	Sylvester *et al.* (1984); Waller & Holland-Bartels (1988)
Perca flavescens	yellow perch	Percidae	Suitable	Waller & Holland-Bartels (1988)
Pomoxis nigromaculatus	black crappie	Centrarchidae	Suitable	Hove and Kapuscinski (2002)
Lepomis macrochirus	bluegill	Centrarchidae	Marginal	Waller & Holland-Bartels (1988)
Esox lucius	northern pike	Esocidae	Marginal	Waller & Holland-Bartels (1988)
Lepomis cyanellus	green sunfish	Centrarchidae	Marginal	Waller & Holland-Bartels (1988); Sylvester *et al.* (1984)
Lepomis macrochirus	bluegill	Centrarchidae	Unsuitable	Sylvester *et al.* (1984)
Lepomis humilis	orange-spotted sunfish	Centrarchidae	Unsuitable	Hove and Kapuscinski (2002)
Lepomis gibbosus	pumpkinseed	Centrarchidae	Unsuitable	Hove and Kapuscinski (2002)
Ambloplites rupestris	rock bass	Centrarchidae	Unsuitable	Hove and Kapuscinski (2002)
Percina maculata	blackside darter	Centrarchidae	Unsuitable	Hove and Kapuscinski (2002)
Cyprinus carpio	common carp	Cyprinidae	Unsuitable	Sylvester *et al.* (1984)
Pimephales promelas	fathead minnow	Cyprinidae	Unsuitable	Waller & Holland-Bartels (1988)
Luxilus cornutus	common shiner	Cyprinidae	Unsuitable	Hove and Kapuscinski (2002)
Semolitus atromaculatus	creek chub	Cyprinidae	Unsuitable	Hove and Kapuscinski (2002)
Nocomis biguttatus	hornyhead chub	Cyprinidae	Unsuitable	Hove and Kapuscinski (2002)
Cyprinella spiloptera	spotfin shiner	Cyprinidae	Unsuitable	Hove and Kapuscinski (2002)
Ictalurus punctatus	northern hognose sucker	Ictaluridae	Unsuitable	Sylvester *et al.* (1984); Hove and Kapuscinski (2002)
Ameiurus melas	black bullhead	Ictaluridae	Unsuitable	Sylvester *et al.* (1984)
Pylodictis olivaris	flathead catfish	Ictaluridae	Unsuitable	Hove and Kapuscinski (2002)
Nocturus gyrinus	tadpole madtom	Ictaluridae	Unsuitable	Hove an`d Kapuscinski (2002)

Table 3. Fishes that have been examined as potential hosts for *L. higginsii*, cont.

Fish species	Common name	Family	Suitability as a host	Reference
Ameiurus natalis	yellow bullhead	Ictaluridae	Unsuitable	Hove and Kapuscinski (2002)
Carpiodes carpio	river carpsucker	Catostomidae	Unsuitable	Sylvester *et al.* (1984)
Catostomus commersoni	white sucker	Catostomidae	Unsuitable	Sylvester *et al.* (1984)
Hypentelium nigricans	northern hognose sucker	Catostomidae	Unsuitable	Hove and Kapuscinski (2002)
Oncorhynchus mykiss	rainbow trout	Salmonidae	Unsuitable	Sylvester *et al.* (1984)
Acipenser fulvescens	lake sturgeon	Acipenseridae	Unsuitable	Hove and Kapuscinski (2002)
Lepisosteus osseus	longnose gar	Lepisosteidae	Unsuitable	Hove and Kapuscinski (2002)
Percopsis omiscomaycus	trout-perch	Percoppsidae	Unsuitable	Hove and Kapuscinski (2002)
Lota lota	burbot	Lotidae	Unsuitable	Hove and Kapuscinski (2002)

Table 4. Water quality data from the St. Croix River at St. Croix Falls, Wisconsin, during 1975-1983. All data are summarized from Graczyk (1986).

Measure	Mean	Range	Number of observations
Total cadmium, ug/L	1.0	<1-3	30
Total chromium, ug/L	9	<20-20	30
Total copper, ug/L	4	<2-24	30
Total mercury, ug/L	0.20	<0.01-0.6	30
Total zinc, ug/L	30	<10-380	29
Alkalinity, mg/L	76	28-110	60
Calcium, mg/L	21	8.5-40	81
Conductivity, umhos	180	65-295	91
Total Nitrogen, mg/L	0.83	0.25-1.8	67
Ammonia Nitrogen, mg/L	0.61	0.13-1.6	89
Dissolved oxygen, mg/L	9.7	6.6-14	68
pH	7.3	6.4-8.3	76
Total phosphorus, mg/L	0.05	0.01-.016	82
Suspended sediment, mg/L	7.5	1-54	72

Table 5. Heavy metals and hydrocarbons in surficial sediments in 1986 from five locations in Pool 10 near Prairie du Chien, Wisconsin. Concentrations are mg/kg dry weight or ppm. Data are unpublished data from the U.S. Army Corps of Engineers (locations 1, 5, 6, 7, and 8).

Measure	Mean	Range	Number of
Heavy metals			
Cd	0.4	<0.3-0.5	10
Cr	11.6	8.3-17.0	10
Cu	8.8	5.0-15.0	10
Zn	41.2	28.9-63.5	10
*Aliphatic hydrocarbons**			
n-pentadecane	0.03	0.02-0.05	10
n-hexadecane	0.02	0.01-0.05	7
n-heptadeccane	0.06	0.02-0.12	10
pristane	0.02	0.01-0.03	4
n-octadecane	0.03	0.02-0.06	10
n-nonadecane	0.07	0.03-0.18	10
n-eicosane	0.03	0.01-0.10	9
Polyaromatic hydrocarbons			
napthalene	0.01	0.01	2
anthracene	0.01	0.01-0.03	5
fluroanthrene	0.04	0.01-0.20	7
pyrene	0.05	0.01-0.27	7
1,2-	0.01	0.01	5
chrysene	0.09	0.01-0.34	5
benzo(b)fluoranth	0.02	0.01-0.03	7
benzo(a)pyrene	0.01	0.01-0.02	7
1,2,5,6-	0.05	0.01-0.16	4
benzo(g,h,i)peryl	0.02	0.01-0.04	5

*In addition to the aliphatic hydrocarbons listed in the table, sediments were also analyzed for n-dodecane, n-tridecane, n-tetradecane, octylcyclohexane, and nonylcyclohexane. Concentrations of these compounds were below the lower level of detection of 0.01 ppm.. Sediments were also analyzed for 20 organochlorine compounds including HCB, BHC, oxychlordane, heptachlor epoxide, t-nonachlor, total PCBs, arochlor 1242, 1248, 1254, and 1260, o, p'-DDE, p, p'-DDE, dieldrin, o, p'-DDD, endrin, cis-nonachlor, o, p'-DDT, p, p'-DDD, p, p'-DDT, and mirex. Concentrations of these organochlorine pesticides were below the lower level of detection of 0.01 ppm (0.05 ppm for total PCBs).

Table 6. List of studies at primary habitats described in the 1983 *L. higginsii* recovery plan.

Site	UMRS Pool	River Mile	References
Sylvan Slough, IL	15	485.5-486	Ecological Analysts (1981b); Blodgett & Sparks (1987b); Cawley (1989); Miller and Payne (2001)
Cordova, IL	14	503-505.5	Stanley Consultants (1988); Miller *et al.* (1990); Miller and Payne (1991,1993,1994,1996a,b, 1997, 2001);
McMillan Is., IA	10	616.4-619.1	Miller *et al.* (1990); Miller & Payne (1996, 2001)
Prairie du Chien, WI/MN	10	634-636	Thiel (1981); Havlik (1983);Duncan & Thiel (1983); Andrew Miller and Barry Payne (U.S. Army Corps of Engineers, in litt. 1984); Miller and Payne (1991, 1992, 1993, 1994, 1995a, 1995b, 1996a, 1996b, 1997, 2001); Holland-Bartels & Waller (1988); Clarke & Loter (1992, 1993, 1994, 1995)
Harper's Slough, IA/WI	10	639-641.1	Duncan & Thiel (1983); Miller & Payne (1996b, 2001); David Heath (Wisconsin Department of Natural Resources, in litt. 1996)
Whiskey Rock, IA	9	655.8-658.4	Miller & Payne (1996b, 2001)
Hudson, WI/MN	St. Croix River	16.2-17.6	Fuller (1980); Heidi Dunn (Ecological Specialists, in litt. 1994); Hornbach *et al.* (1995); Heath *et al.* (2001)

V. FIGURES

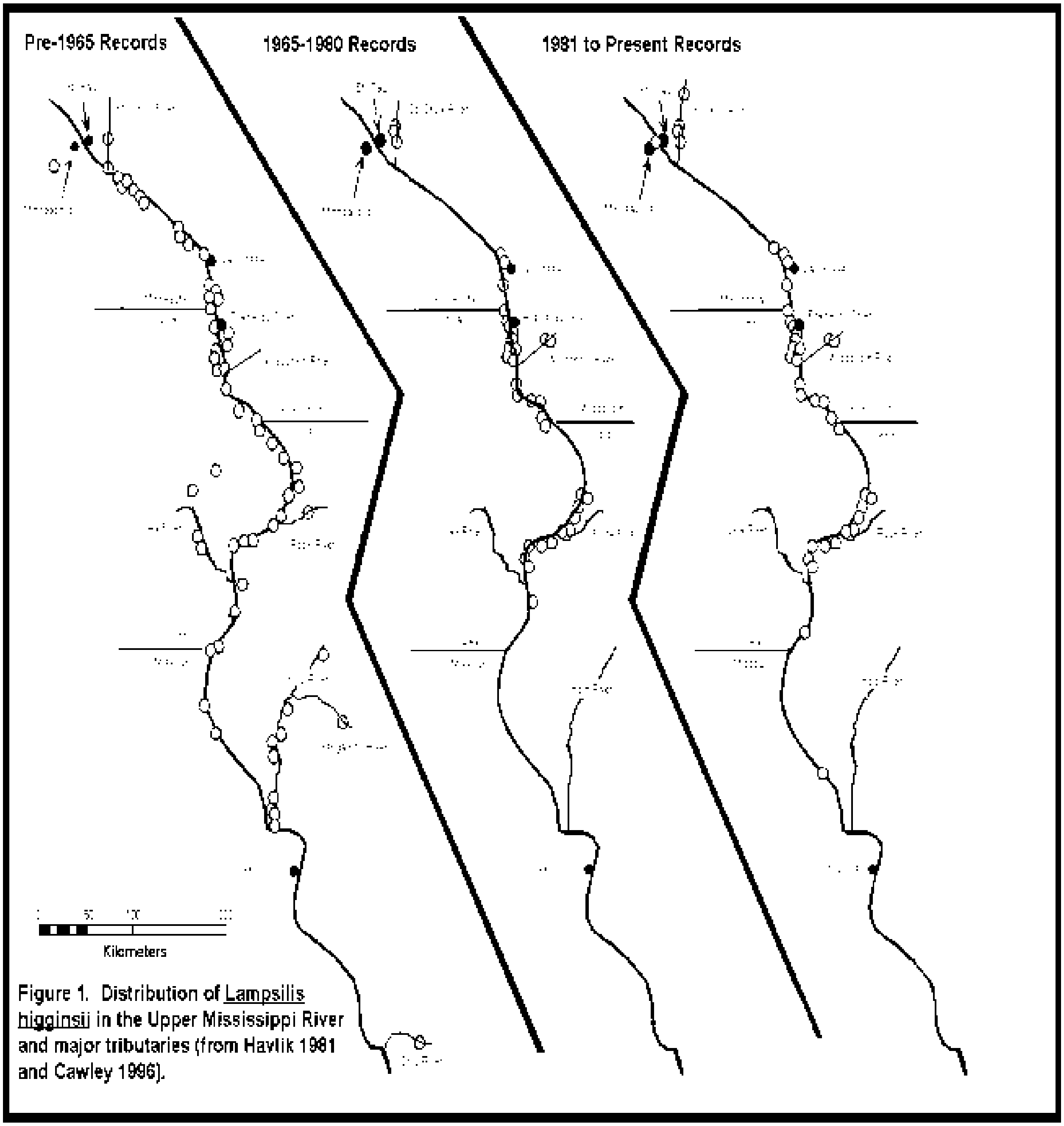

Figure 1. Distribution of Lampsilis higginsii in the Upper Mississippi River and major tributaries (from Havlik 1981 and Cawley 1996).

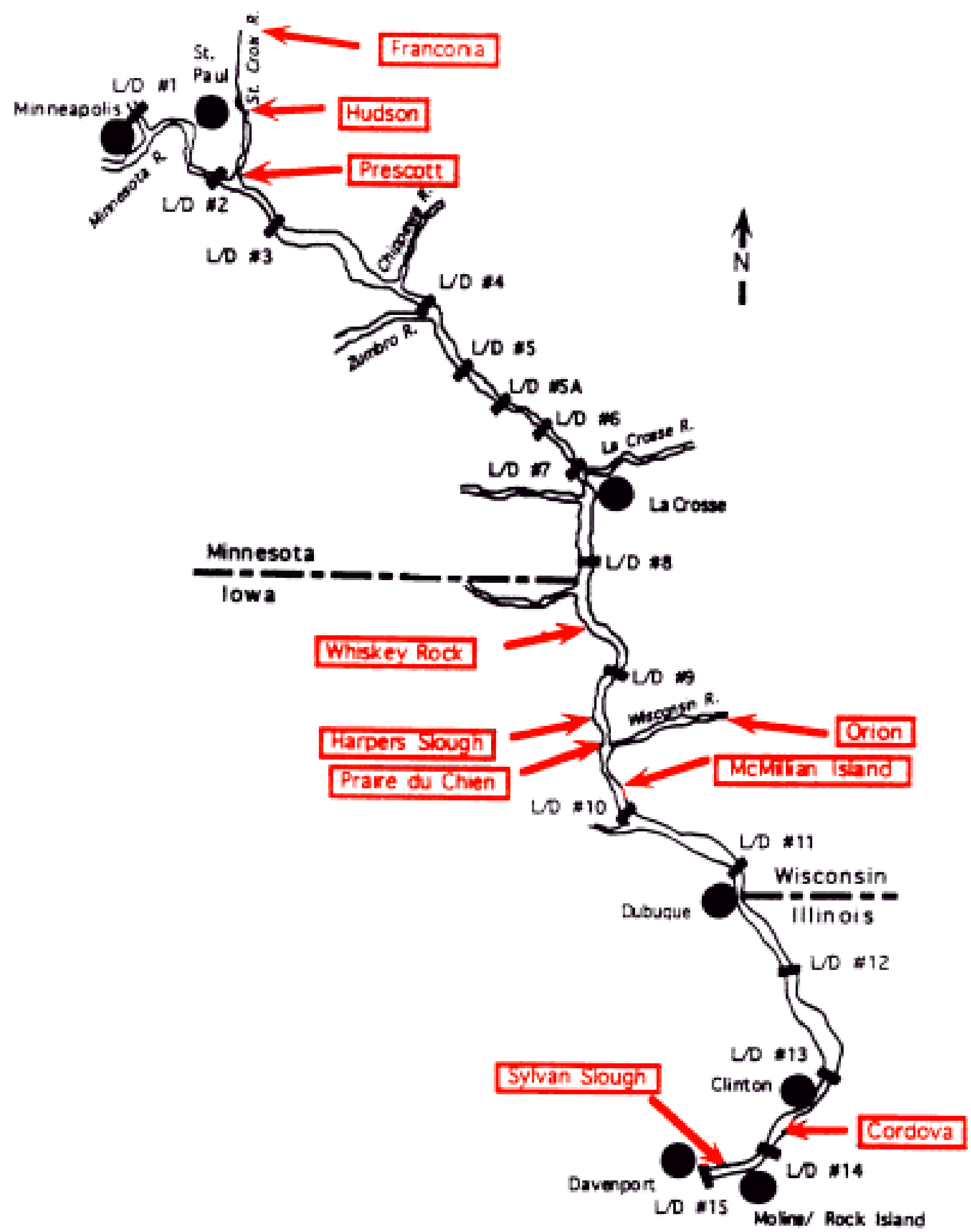

Figure 2. Recommended Essential Habitat Areas for Higgins' Eye Pearlymussel.

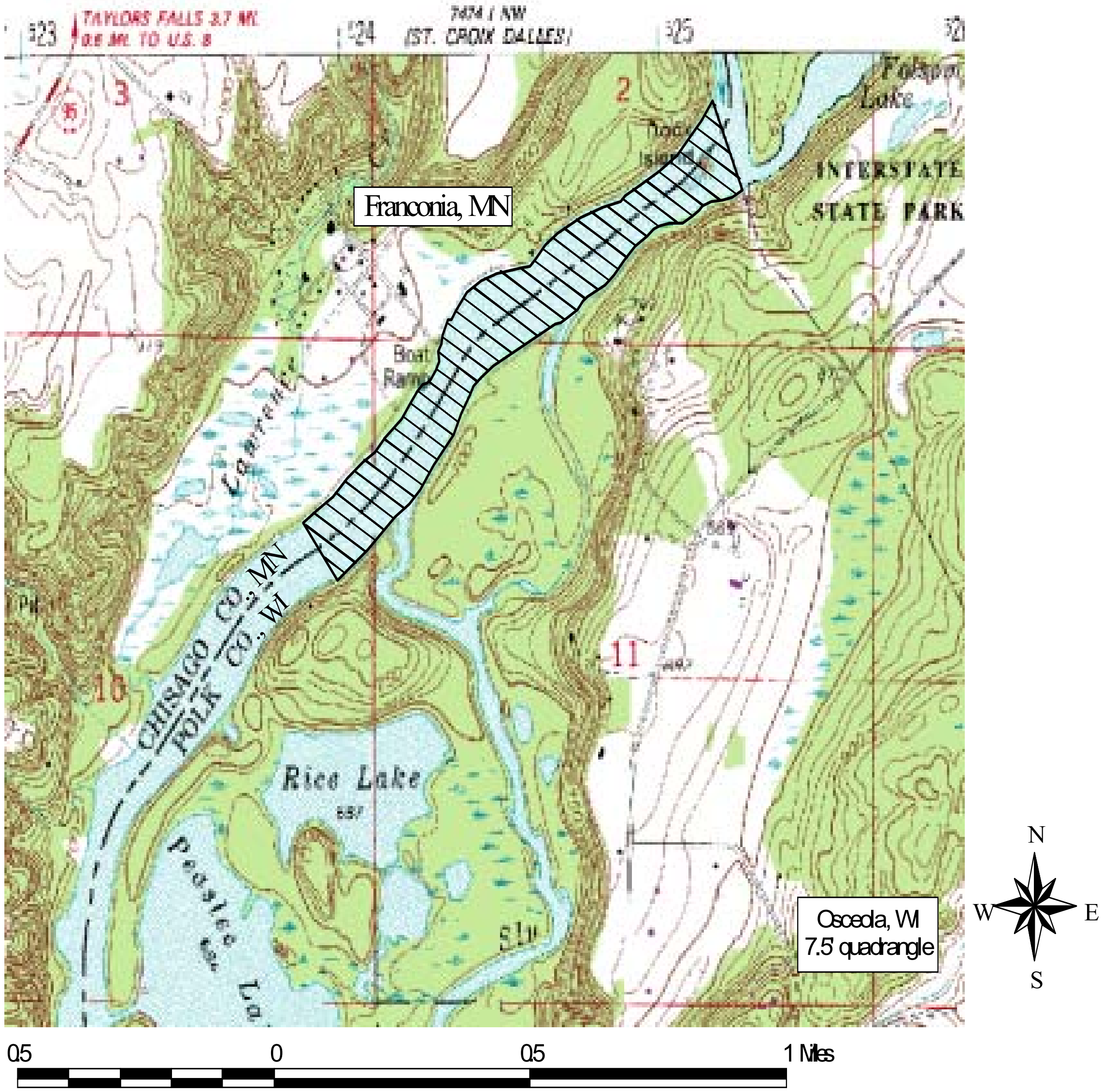

Figure 3. Essential Habitat Area at Franconia, Minnesota, St. Croix River, Chisago County, Minnesota, and Polk County, Wisconsin.

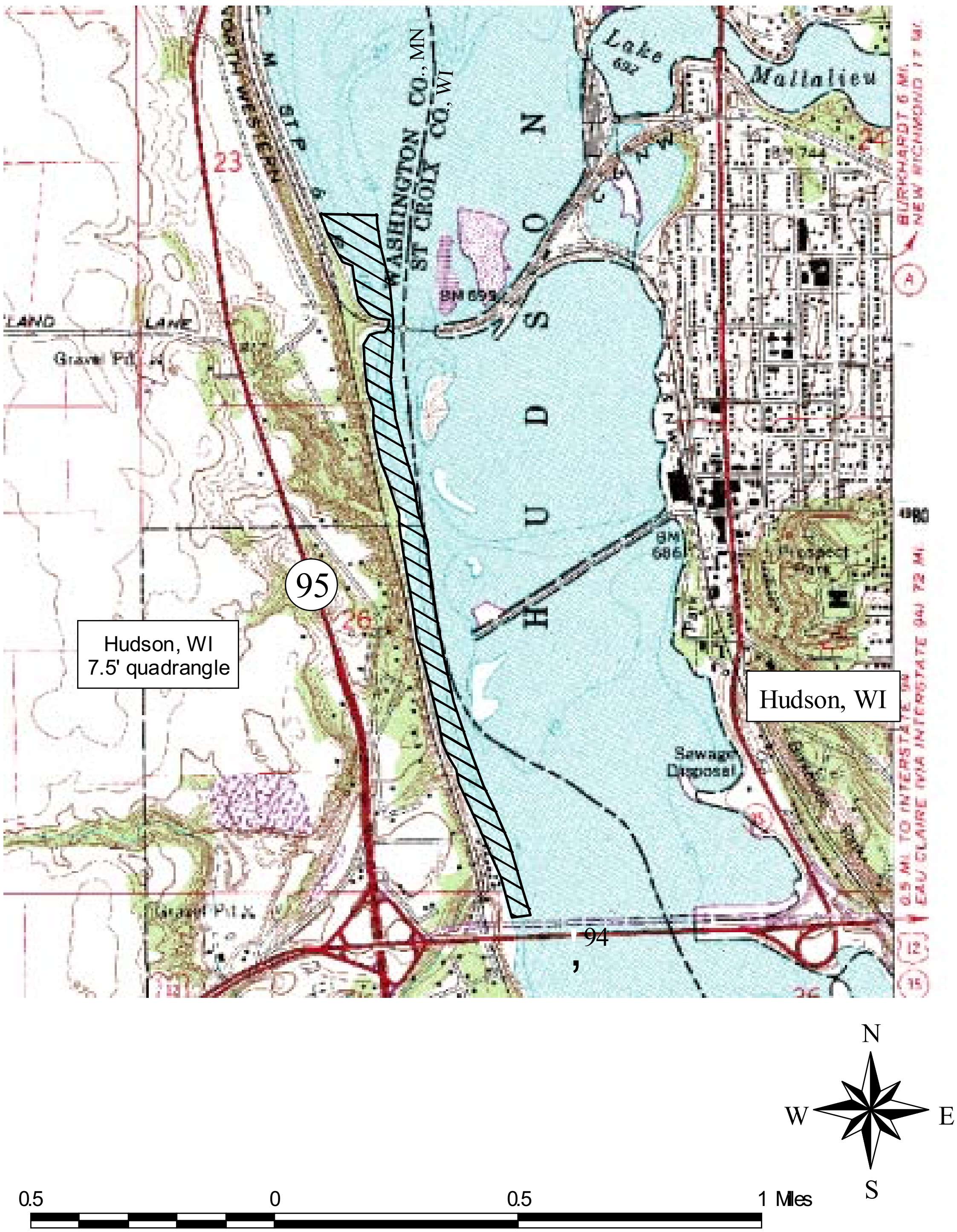

Figure 4. Essential Habitat Area at Hudson, Wisconsin, St. Croix River Washington County, Minnesota.

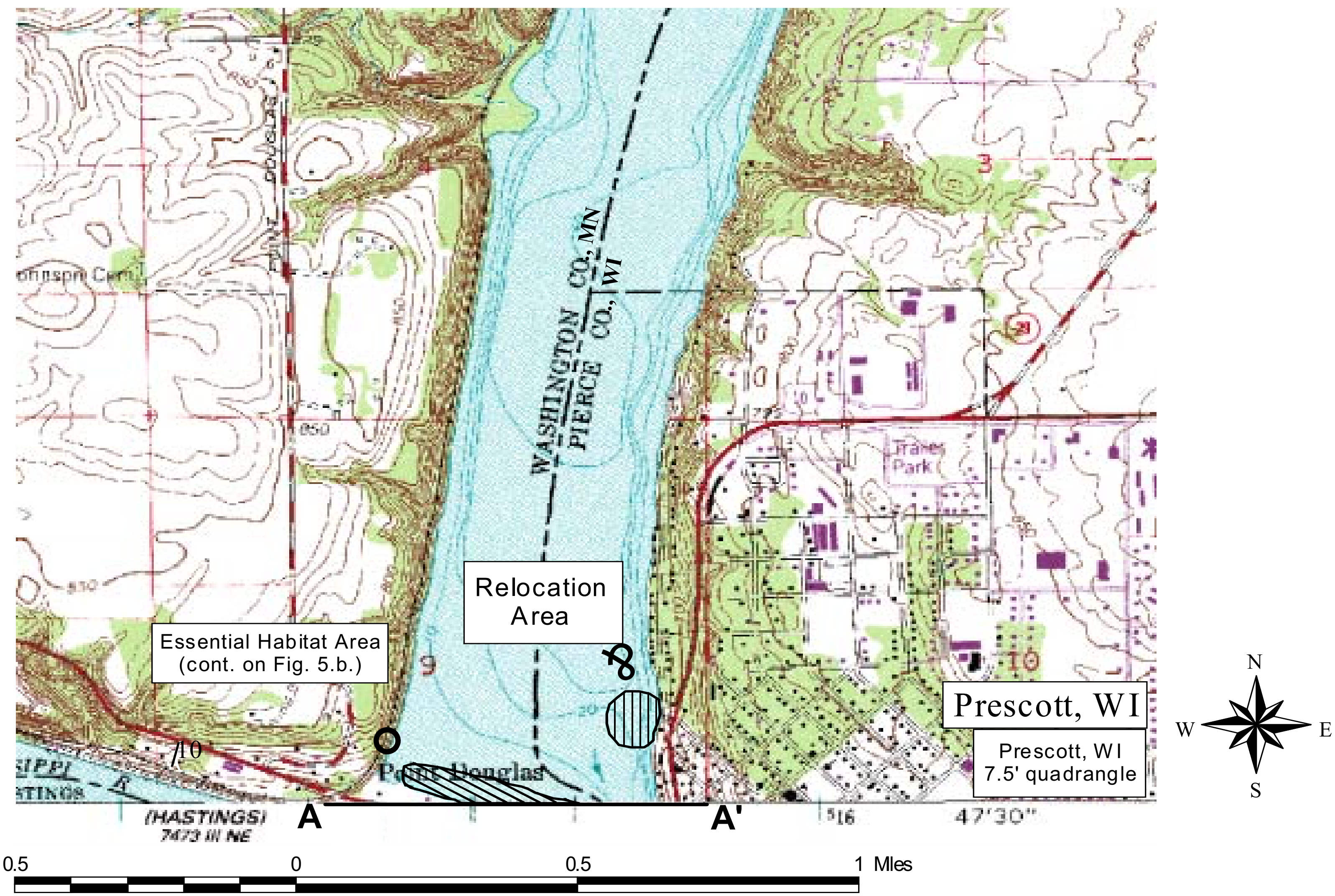

Figure 5.a. Essential Habitat Area at Prescott, Wisconsin, St. Croix River, Washington County, Minnesota, and Pierce County, Wisconsin. Match line A-A' to Figure 5.b.

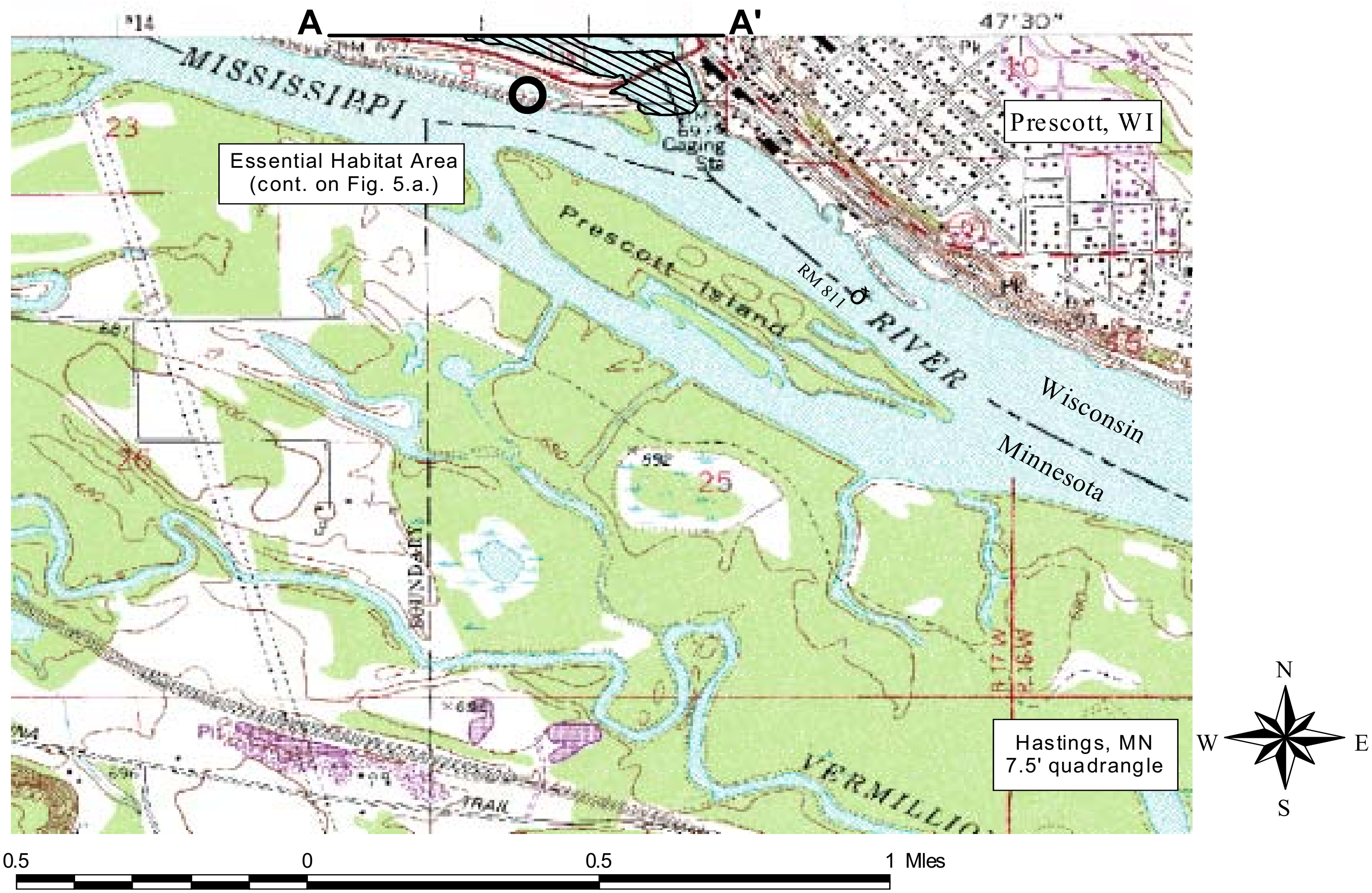

Figure 5.b. Essential Habitat Area at Prescott, Wisconsin, St. Croix River, Washington County, Minnesota, and Pierce County, Wisconsin. Match line A-A' to Figure 5.a.

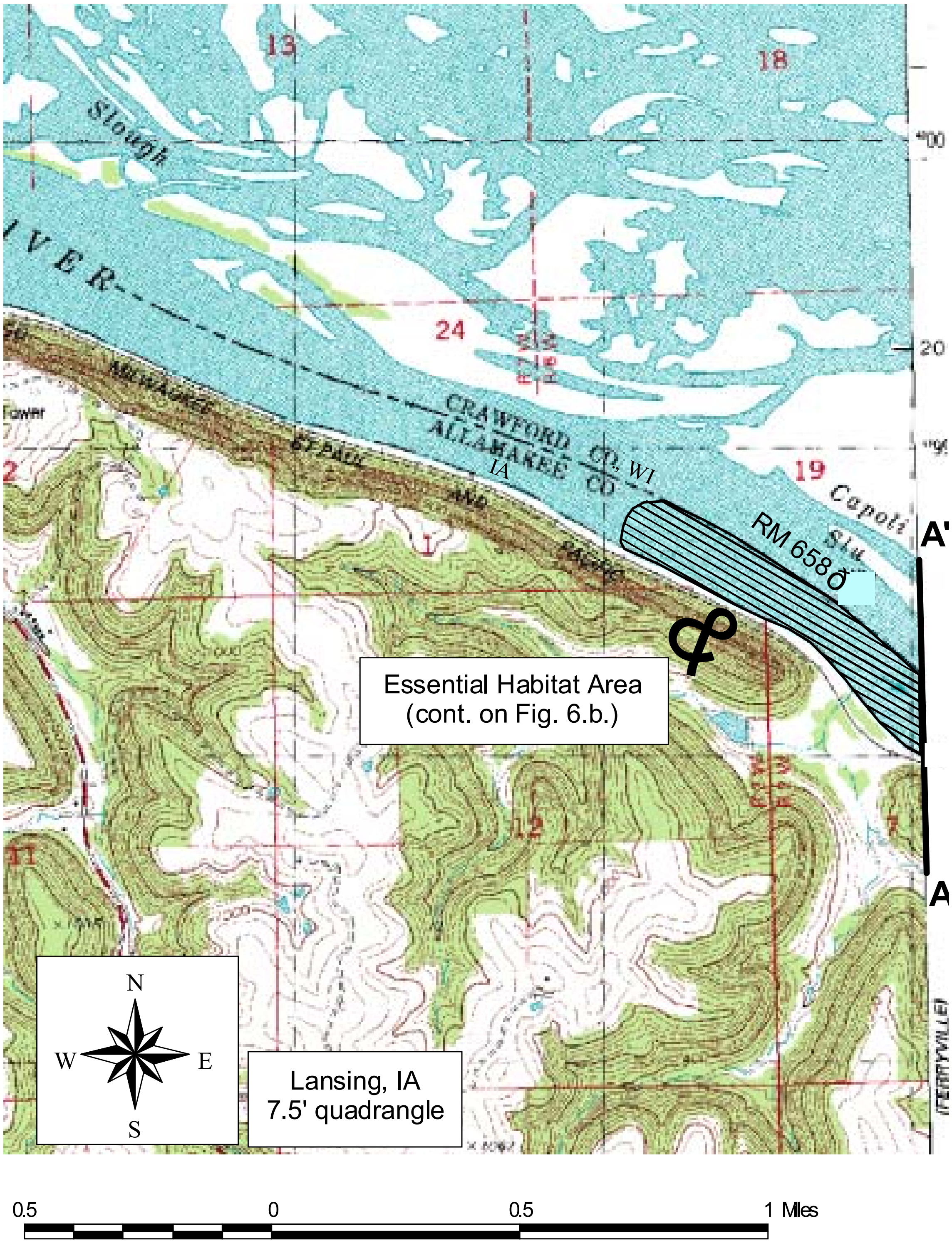

Figure 6.a. Essential Habitat Area at Whiskey Rock, Iowa, Pool 9, Mississippi River, Allamakee County, Iowa, and Crawford County, Wisconsin. Match line A-A' to Figure 6.b.

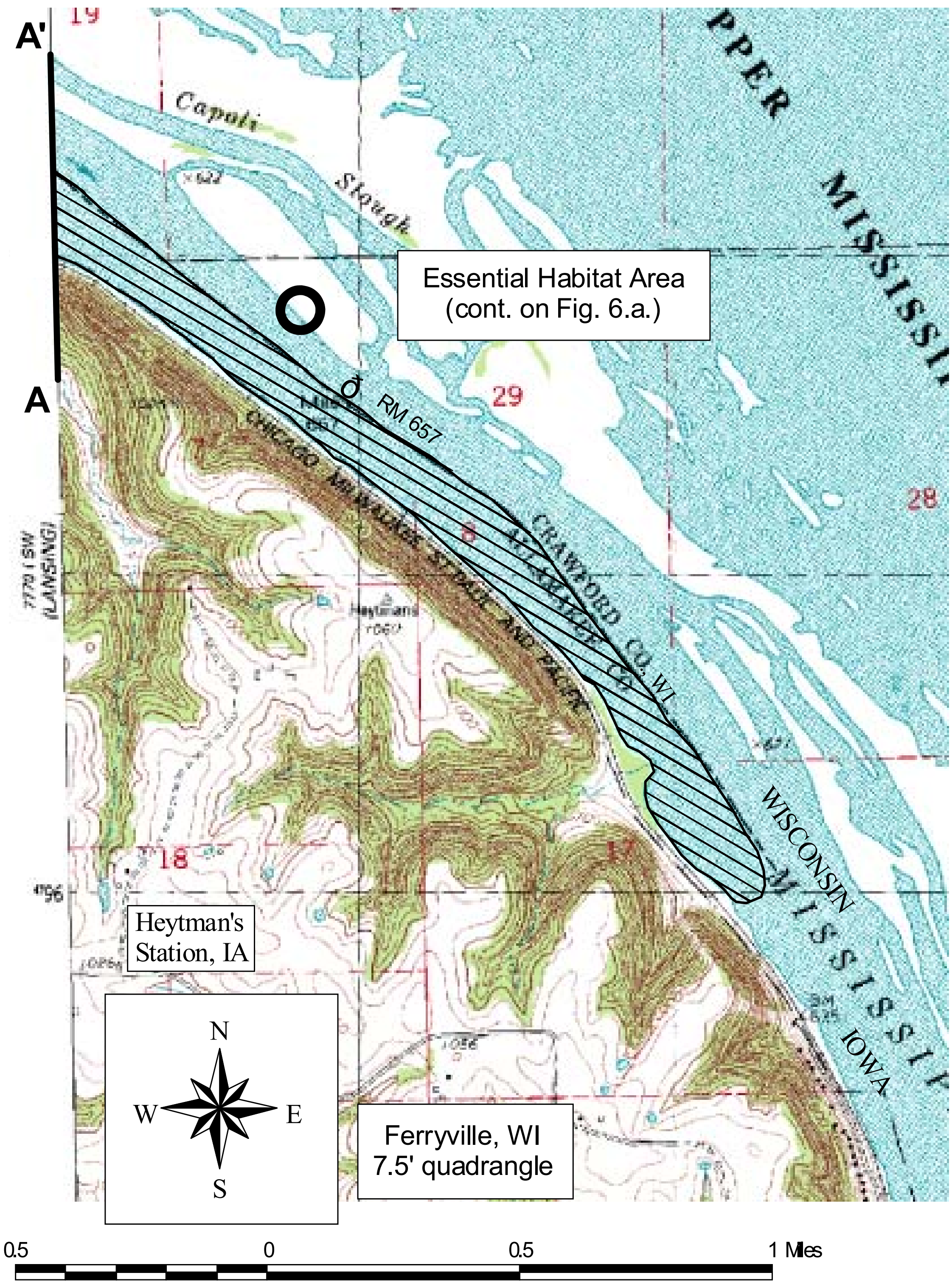

Figure 6.b. Essential Habitat Area at Whiskey Rock, Iowa, Pool 9, Mississippi River, Allamakee County, Iowa, and Crawford County, Wisconsin. Match line A-A' to Figure 6.a.

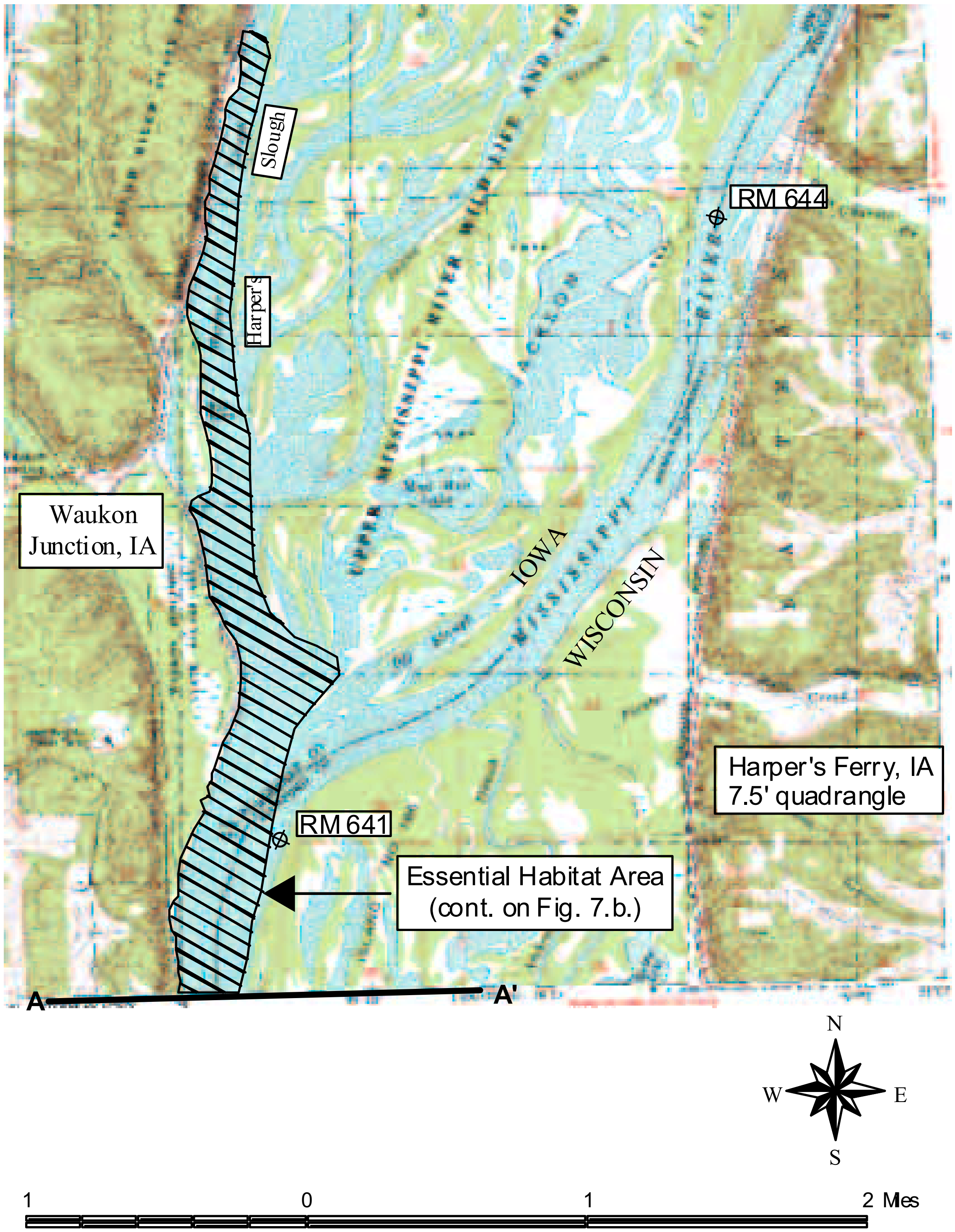

Figure 7.a. Essential Habitat Area at Harper's Slough, Pool 10, Mississippi River, Allamakee County, Iowa, and Crawford County, Wisconsin. Match line A-A' to Figure 7.b.

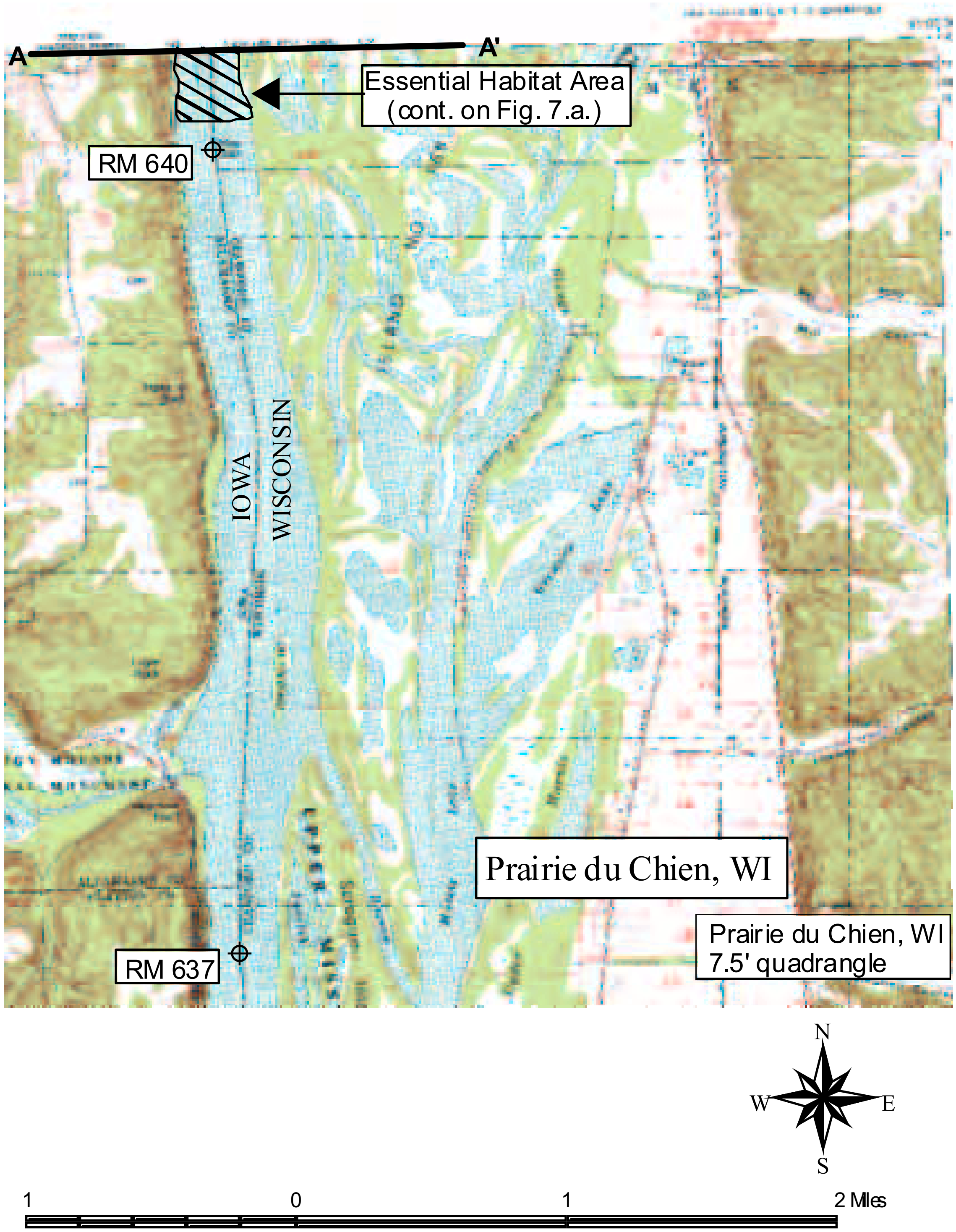

Figure 7.b. Essential Habitat Area at Harper's Slough, Pool 10, Mississippi River, Allamakee County, Iowa, and Crawford County, Wisconsin. Match line A-A' to Figure 7.a.

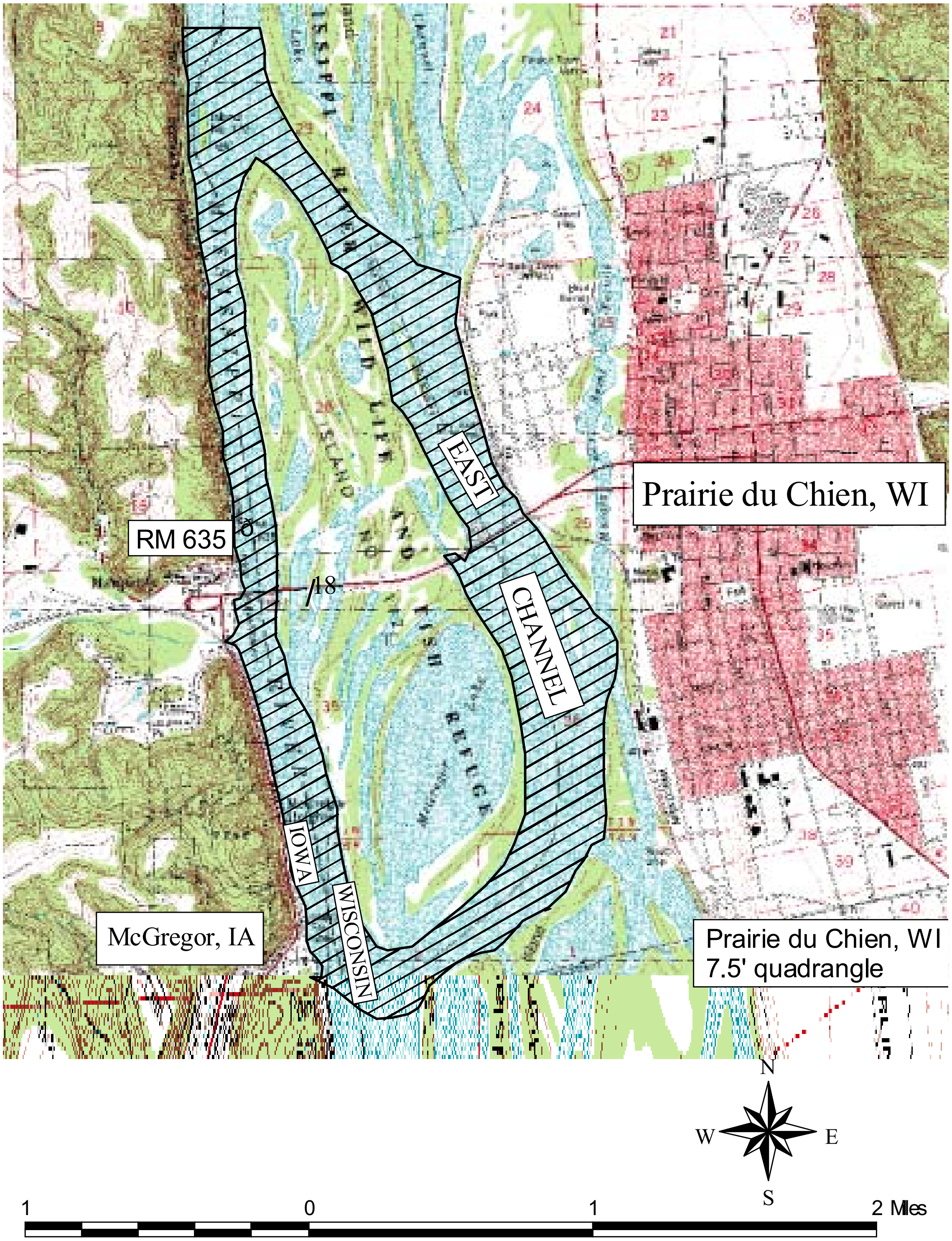

Figure 8. Essential Habitat Area at Prairie du Chien, Wisconsin, Pool 10, Mississippi River Clayton County, Iowa, and Crawford County, Wisconsin.

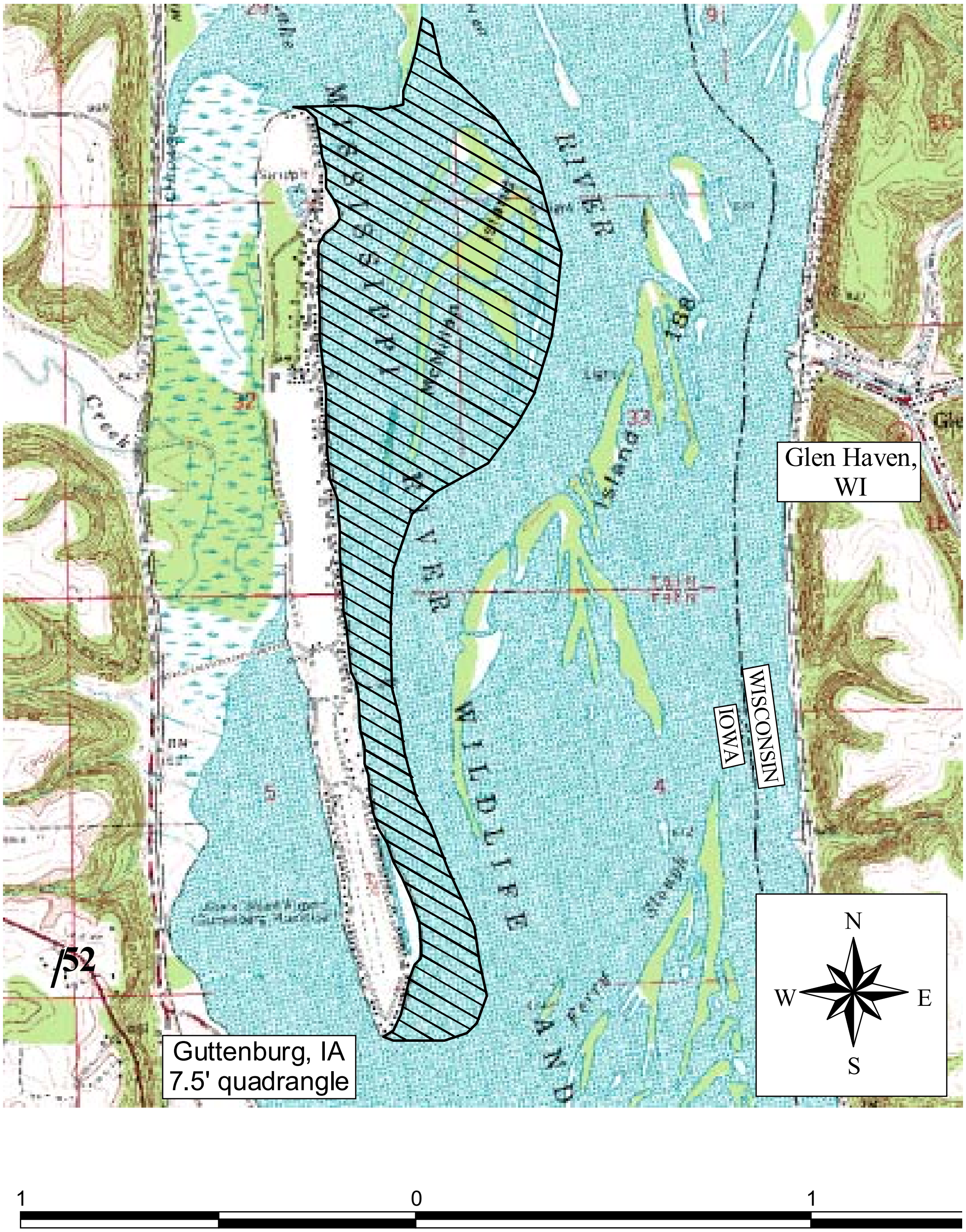

Figure 9. Essential Habitat Area at McMIllan Island, Pool 10, Mississippi River, Clayton County, Iowa.

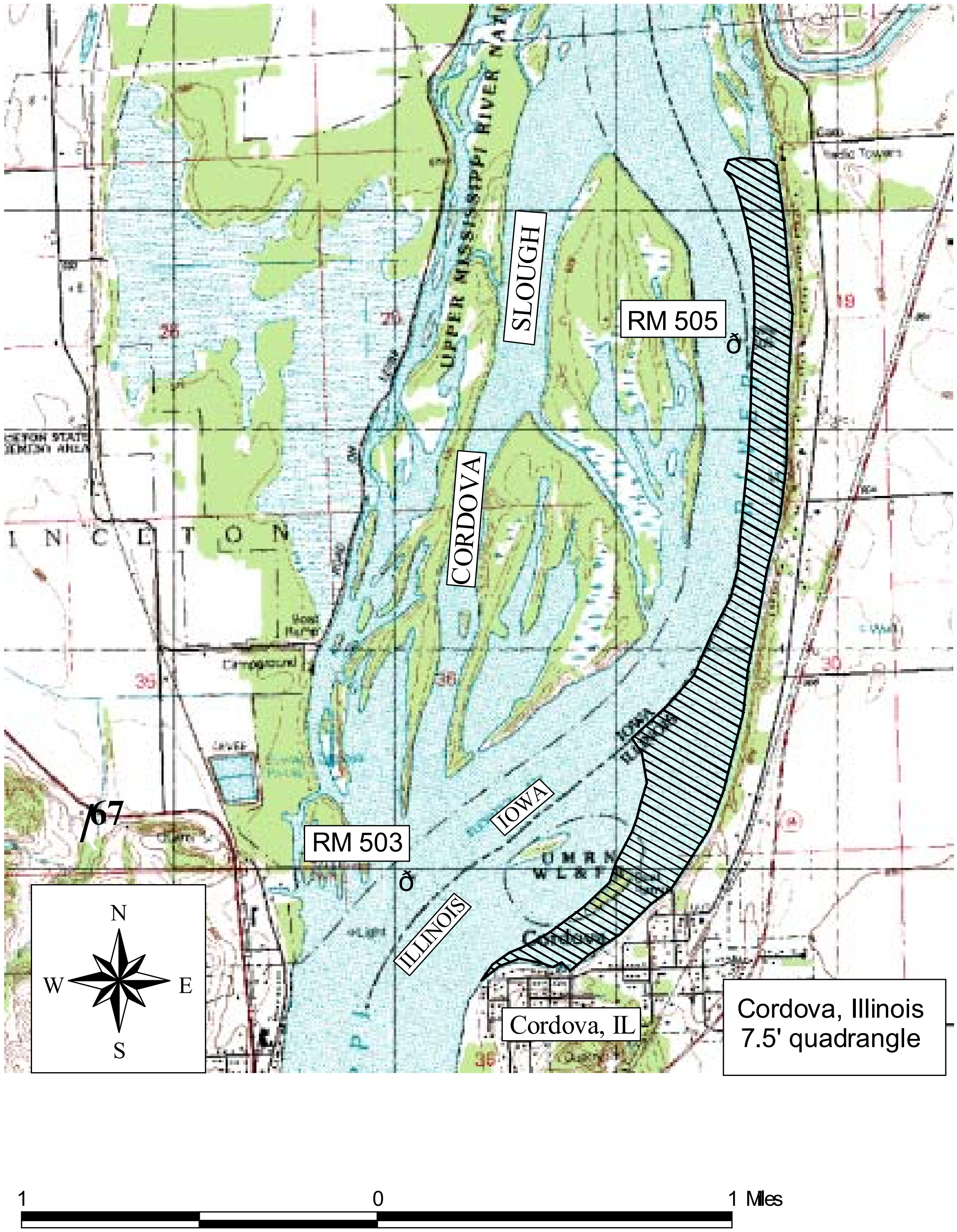

Figure 10. Essential Habitat Area at Cordova, Illinois, Pool 14, Mississippi River, Rock Island County, Illinois.

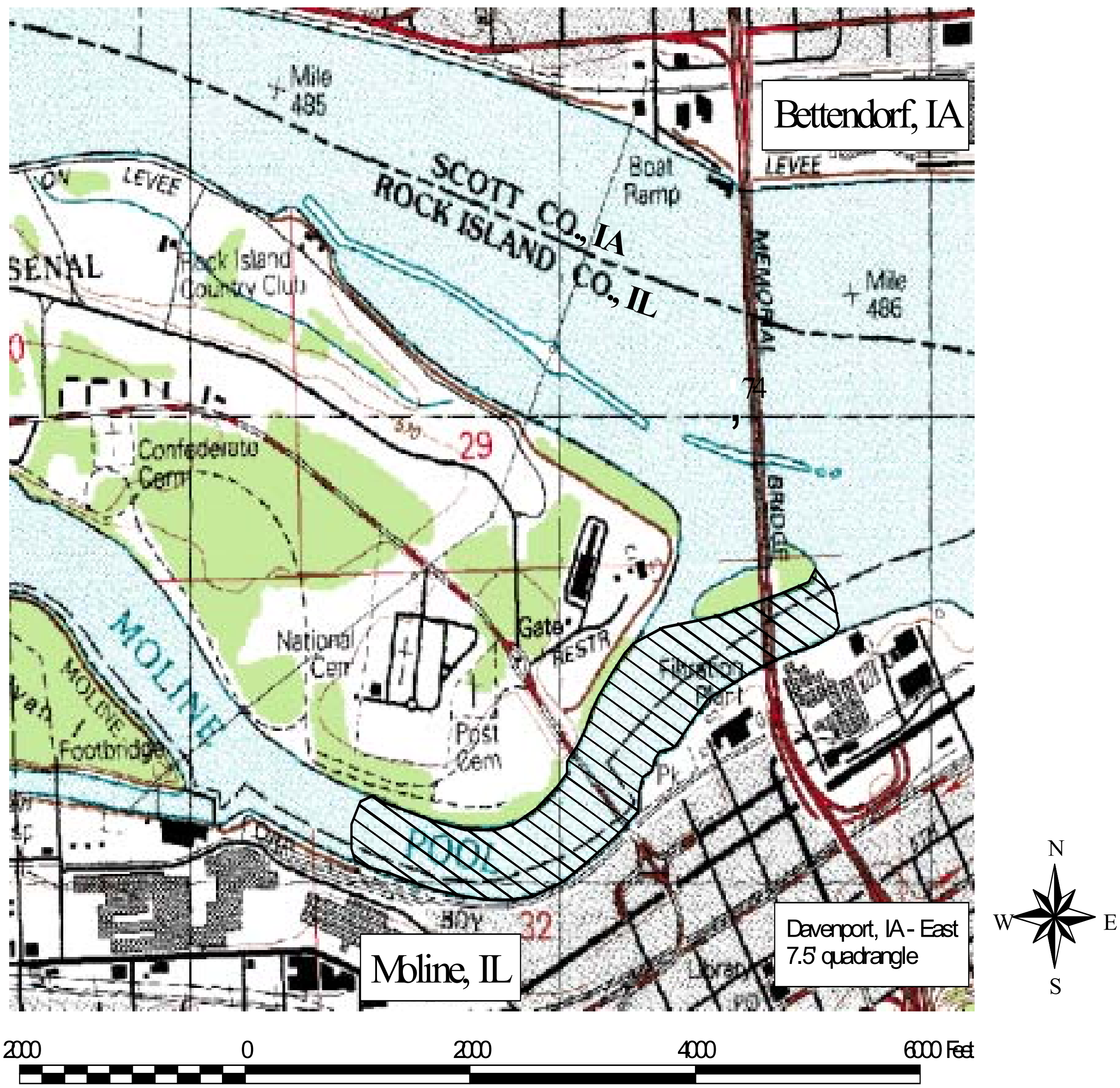

Figure 11. Essential Habitat Area at Sylvan Slough, Pool 15, Mississippi River, Rock Island County, Illinois.

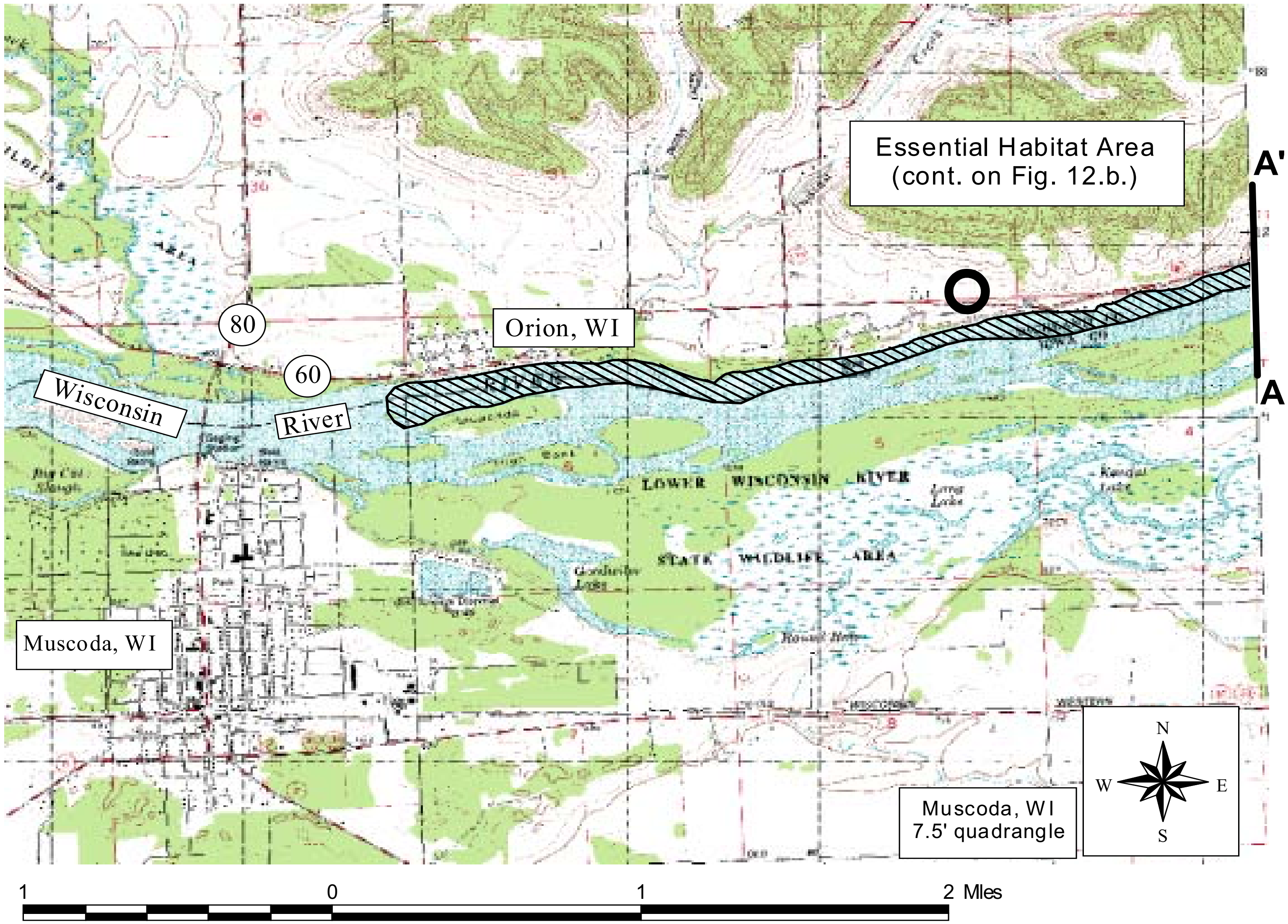

Figure 12.a. Essential Habitat Area at Orion, Wisconsin River, Richland and Iowa Counties, Wisconsin. Match line A-A' to Figure 12.b.

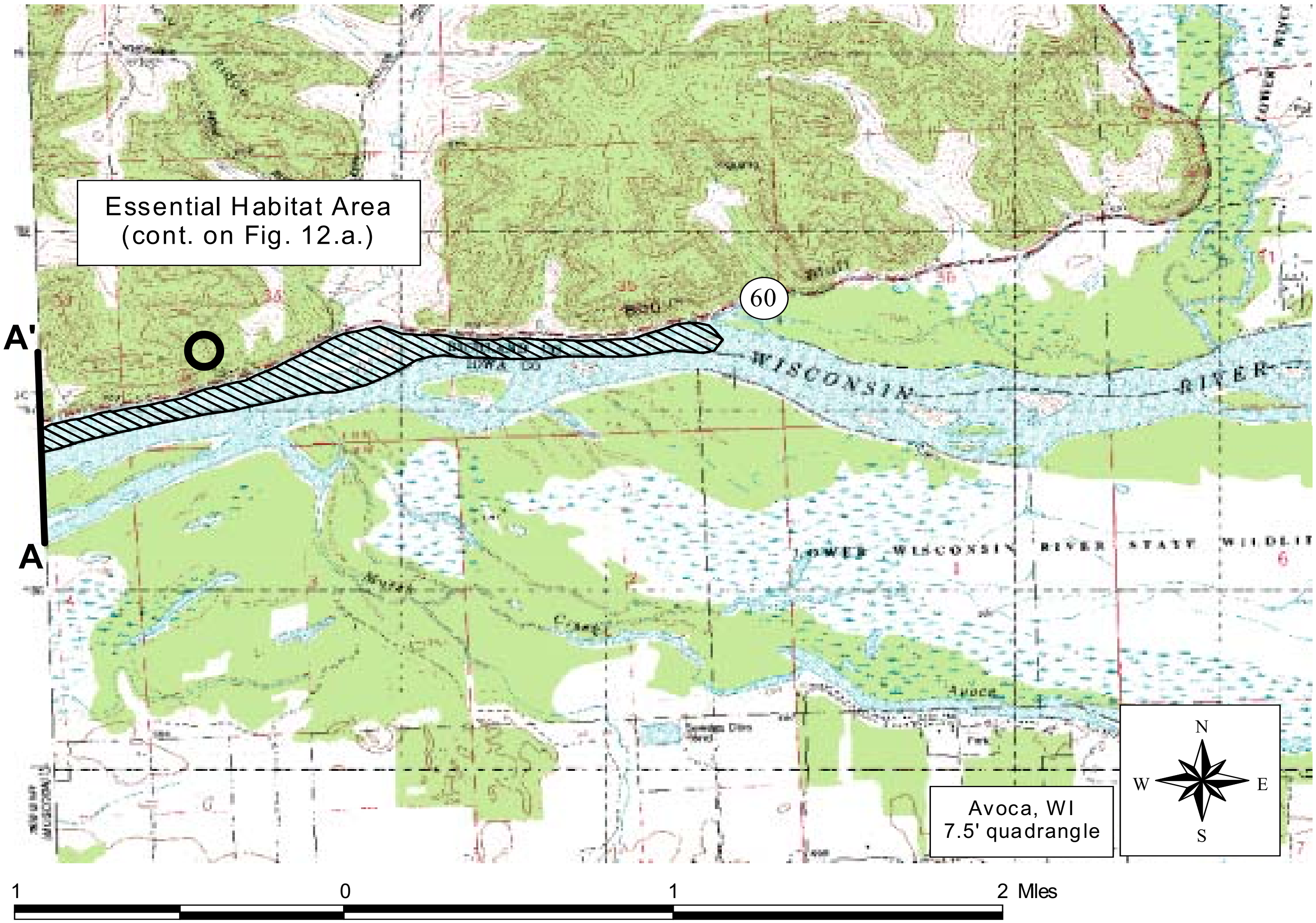

Figure 12.b. Essential Habitat Area at Orion, Wisconsin River, Richland and Iowa Counties, Wisconsin. Match line A-A' Figure 12.a.

VI. APPENDICES

Appendix A. Peer Review and Peer Contributors

The U.S. Fish and Wildlife Service extends special thanks to various experts, in addition to the experts on the recovery team, who reviewed earlier drafts and/or provided their information or expert recommendations for the draft Higgins' Eye Pearlymussel Revised Recovery Plan. This peer input was invaluable in bringing current biological information on the species and ecosystem management concepts to the current draft of the plan.

The following expert peers provided review and/or scientific information to the recovery team:

Dr. G. Thomas Watters
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Athens, Georgia

Appendix B. Higgins' Eye Pearlymussel Technical/Agency Draft Revised Recovery Plan Review

The Service published a notice of availability of a technical/agency draft revised plan on June 22, 1998 (63 FR 33944) and transmitted the document for public review and comment shortly thereafter. The Service and individual members of the Higgins' Eye Recovery Team received substantial formal and informal comments addressing a variety of format, content, and organizational points of the technical/agency draft. The team carefully considered all comments received. As a result of the technical/agency draft plan comment period, the recovery team was able to substantially improve the revised plan by incorporating the latest available biological information on the species and the measurement of its recovery, and by improving the flexibility and practicality of the plan's tasks and recovery criteria.

The following individuals/agencies provided comments on the 1998 technical/agency draft revised plan:

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Comments and individual responses are maintained in the administrative record at the U.S. Fish and Wildlife Service, 4101 E. 80th Street, Bloomington, Minnesota 55425-1665.